Interpersonal influences in human visual attention: from behaviour to EEG

by

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Abstract

Human evolution has shaped us into social animals, who are continually immersed in social interactions, constantly performing tasks with others and sharing our reality with them (Dunbar, 2003; Tomasello, Carpenter, Call, Behne, & Moll, 2005). For many of these interactions to be successful, it is necessary to pay attention to the same spatial locations with other individuals. Surprisingly however, this specific low-level aspect of our social life (i.e., attending to the same spatial locations with others) is not well understood. The present PhD work aims at contributing to this understanding by investigating whether paying attention towards the same spatial location with another person modulates one's attention performance, along with its social, cognitive, and neural implications.

In this line, the classic visuospatial sustained attention paradigm (e.g., Eimer, 1996; Mangun & Hillyard, 1988; Mangun & Buck, 1998) was adapted so it could be independently performed by two people (a dyad) sitting next to each other, to examine how visual attention performance (reaction times, RTs) is interpersonally modulated when an experiment partner is paying attention to the same or a different spatial location (aka., dual attention paradigm). In this paradigm (Experiment 1), participants performed a visual go/no-go task, responding to visual targets while attending to the same vs. different spatial location than the experiment partner. A typical attention effect was present in RTs (i.e., faster responses to targets appearing at the attended locations compared with those at the unattended locations) when the dyad attended to different locations. This attention effect, however, was significantly reduced when the participants shared the attentional locus (aka., dual attention effect). This pattern was reversed when single participants performed the task in isolation (Experiment 2),

suggesting that the reduction in the attention benefit was socially driven between individuals (interpersonally). Additional experiments showed that the dual attention effect persisted under an increased perceptual load (Experiment 3), was not modulated by the group membership status attributed to the task partner (i.e., social closeness; Experiment 4), and disappeared once the partner was performing the task from a separate room (i.e., physical closeness; Experiment 5).

Finally, an electroencephalography (EEG) study (Experiment 6) investigated the neural underpinnings of the dual attention effect, focusing on the information processing stage(s) influenced by dual attention. The aim was to understand whether the dual attention effect took place at a sensory level vs. a cognitive control stage. Event-related potentials (ERPs) and neural oscillations suggested that the effect was driven by a cognitive control process, and also showed an enhancement in the early sensory level information processing in the brain. Both the N2b ERP component and mid-frontal theta oscillations pointed towards a stronger need for control when sharing the attentional locus with another person in the dual attention task, while the P1 component yielded an enhancement in the attention effect in the attention sharing condition. The P1 effect may be top-down driven through alpha band long-range communication from prefrontal to posterior areas. Likely higher order processing related accounts were proposed for the current findings (e.g., linked to response inhibition, or mentalising/monitoring others). The current thesis made the first attempt to place dual attention as a bridge between the general shared attention perspective (Stheynberg 2015) and the overt behavioural interplay characterising joint attention and joint action. In addition, the present results could have ubiquitous real-life implications, and may give us some clues about how to optimize daily performance in dual-attention-like environments (e.g., classrooms/working spaces).

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Author’s Declaration

I hereby declare that the work presented in this thesis has not been and will not be, submitted in whole or in part to another University for the award of any other degree.

Signature:

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INTRODUCTION AND LITERATURE REVIEW

Human evolution has shaped us into social animals, who are continually immersed in social interactions, regularly performing tasks with others and sharing our reality with them (Dunbar, 2003; Tomasello, Carpenter, Call, Behne, & Moll, 2005). For many of these interactions to be successful, it is necessary to pay attention to the same spatial locations with other individuals. We do this since childhood, while trying to learn from our parents, and continue doing it throughout our lifetime. A group of students attending together to a lecture, or a couple of workers monitoring a product in an industrial assembly chain are only a few examples where this ubiquitous "phenomena" occurs. Surprisingly however, the social, cognitive, and neural implications of this specific low-level aspect of our social life (i.e., attending to the same spatial locations with others) are not well understood. The present PhD work aims at contributing to this understanding by investigating whether paying attention towards the same spatial location with another person modulates one's attention performance.

Due to the limited processing capacity of the human brain, attention has evolved as a way to efficiently select relevant information from the environment (Pashler, Johnston, & Ruthruff, 2001), determining what merits to be processed by the brain. This core cognitive mechanism allows us to select what "matters" out of the vast amount of information surrounding us. This mechanism however, as human cognition in general, develops and materialises in a social context. Therefore, it should not be striking that several research outcomes have shown that humans are strongly influenced by other individuals during interpersonal interactions (Gobel, Kim, & Richardson, 2018; Hari, Henriksson, Malinen, & Parkkonen, 2015; Sebanz, Bekkering, & Knoblich, 2006), to the point that it has been suggested that social interactions may play a central role in human brain function (Hari et al., 2015; Hari & Kujala, 2009).

Considering that an important amount of the information around us is social in nature (e.g., other persons or somehow related to them), it would not be surprising that the mechanism we developed to decide what is processed by our brains (i.e., attention), and human cognition in general, could be shaped by social context and socially relevant information, or influenced by other individuals in our environment. In this introductory section I will present some of the theories and empirical findings available to date regarding these interpersonal influences and the impact of social context on cognitive processes, particularly in the attention mechanism. I will show that although substantial evidence has been provided for interpersonal social influences on human cognition, little is known about the influence on basic attentional processes. This PhD thesis contributes to the latter by investigating how visual attention performance is changed by the knowledge that another person is paying attention towards the same spatial locations with us, in the absence of explicit interactions, while providing insights about the factors modulating this influence, and the neural mechanisms behind it.

In the remaining of this chapter, literature covering topics including visuospatial attention, joint performance, and joint/shared attention research will be introduced, as well as some insights from neuroimaging and neurophysiology, with a particular focus on electroencephalography (EEG) research relevant to the above-mentioned topics. Afterwards, the motivation and aims behind this PhD work will be presented along with an outline of the present Thesis.

1.1. Visuospatial attention

Our mind is constantly exposed to an enormous amount of information from the environment we are immersed in. Given that the cognitive and neural processing resources of our brain are limited, visual attention allows to prioritise what prevails out of all the visual information available, and selects what comes to be eventually processed by the brain (Pashler, Johnston, & Ruthruff, 2001). According to the currently prevalent notion (biased-competition hypothesis; see (Beck & Kastner, 2009; Desimone & Duncan, 1995; Kim & Kastner, 2019), visual stimuli (e.g., objects, events, spatial locations) compete for the limited available neural resources, and the visual system selectively filters relevant from irrelevant information by biasing the neural responses in favour of the attended stimuli. This means that neural populations with receptive fields at the attended location remain active or increase their activity, while the rest reduce their activity or become suppressed (Desimone & Duncan, 1995). By enhancing representations of relevant aspects of the visual environment and suppressing the irrelevant ones, visual attention allow us to get information that ultimately guide our brain processes and behaviour (Carrasco, 2011).

Visuospatial attention in particular, refers to the ability of shifting the focus of attention towards a specific location in space, or away from it (Posner, 1980). This orienting of visual attention allows the prioritisation and selection of information within the relevant (attended) visual field. Visuospatial attention can be oriented in two ways (for reviews see Carrasco, 2011; Chica, Martín-Arévalo, Botta, & Lupiáñez, 2014; Nobre, 2018). On the one hand, endogenous attention (aka., voluntary, sustained, goal-driven or top-down attention) refers to our ability to deploy visual attention at will towards a particular spatial location, according to a set of instructions or behavioural goals. Alternatively, exogenous attention (aka., involuntary, transient, stimulus-driven or bottom-up attention) refers to the automatic/involuntary deployment of attention towards spatial locations where sudden/unexpected/salient events take place. The interplay between these two types of visuospatial attention allow us to select relevant information in our environment according to our current goals (e.g., focus on the street while riding a bike), and to process unexpected/salient changes within this environment (e.g., a barking dog approaching our bike), allowing us to subsequently respond to them accordingly (e.g., avoiding the dog).

Two “classic” experimental paradigms have been extensively used to study endogenous and exogenous spatial orienting of attention: the Posner spatial orienting task (Posner, 1980) and the sustained visuospatial attention paradigm (e.g., Eimer, 1996; Mangun & Hillyard, 1988; Mangun & Buck, 1998). The former one can be employed to study both exogenous and endogenous orienting, while the later focuses on endogenous attention. In the basic form of the Posner task, a participant sat in front of a computer screen is asked to detect or discriminate a visual target stimulus while holding a central fixation (i.e., without moving her eyes; but see Chica, Klein, Rafal, & Hopfinger, 2010 for an example where eye movements were allowed). The target stimulus appears peripherally, at one of two locations in the screen. Before the appearance of the target though, a cueing stimulus is displayed. This cue is the key element guiding visual attention in the task. In endogenous attention manipulations, the cue is typically an informative symbol (e.g., a central dot cueing a specific location according to its colour: red for the right side, blue for the left) presented centrally in the screen. This symbol predicts the location where the subsequent target is likely to be displayed (e.g., 75% of the times, also known as cue validity). Thus, the participant can use this information to voluntarily shift her focus of attention to a particular spatial location accordingly. Under this experimental setting, participants tend to respond faster and more accurately to targets appearing at the previously cued location (i.e., valid), than to the uncued one (i.e., invalid). This reaction times (RTs) difference between valid and invalid trials is known as attention effect (Posner, 1980), and it reflects the behavioural benefit of allocating attention towards a particular spatial location. Neutral (non-informative) cues, instead, do not encourage systematic attention shifts. However, by comparing the responses (RTs and accuracy) to valid vs. neutral trials one could obtain a cleaner quantification of the benefit of attention deployment towards the cued location. In a similar way, the costs of taking attention away from a spatial location can be estimated by comparing the performance to invalid vs. neutral trials. The facilitation effect of central cues is observed behaviourally ~300ms after the cue is displayed, once the participant has had enough time to process the information conveyed by the cue and shifts the locus of attention correspondingly (Remington & Pierce, 1984), and can be sustained for several seconds (Posner, 1980).

In exogenous attention manipulations (see Chica, Martín-Arévalo, Botta, & Lupiáñez, 2014), the cue is a transient, non-informative, peripheral stimulus appearing typically at one of two locations. This cue acts as a salient event that primes attention towards a specific spatial location (i.e., the location where the cue is displayed), enhancing the processing of the visual stimuli subsequently appearing at (or close to) that location, relative to those at the invalid side. As for the endogenous version of the task, after the cue presentation, the target is displayed either at the valid or invalid location, with similar implications in terms of RTs, accuracies, and the measurement of the cost and benefits of attention. This cueing effect however, is not always "facilitatory". The facilitation effect observed with peripheral cues is early and transient (respect to the endogenous case). It can be obtained ~50ms after the cue presentation, but fades quite fast, disappearing ~200 to 300 ms. After ~300ms, an inhibitory effect is obtained, with a performance impairment (i.e., slower RTs and/or lower accuracies) at the valid location, compared to the invalid one. This inhibitory mechanism keeping attention away from previously attended events/locations is known as Inhibition Of Return (IOR; Klein, 2000; Klein & Taylor, 1994; Lupiáñez, Klein, & Bartolomeo, 2006; Posner, Rafal, Choate, & Vaughan, 1985). Importantly, the time between the cue and target presentation (SOA, or Stimulus-Onset Asynchrony) is not the only relevant parameter modulating the outcome of the orienting task. There are many variables that need to be selected when designing this kind of experimental paradigm. Besides the SOA, parameters like the cue type (endogenous vs. exogenous), the cue validity, the cue and target durations, the cue and target physical characteristics, whether covert vs.

overt attention shifts are allowed, and the type of task (e.g., discrimination vs. detection), among others, need to be defined. It is beyond the scope of this introduction to provide a detailed explanation of these parameters and their implications in spatial orienting, but see Chica et al. (2014) for a review and tutorial on how to design and interpret visuospatial attention experiments.

Finally, in the sustained visuospatial attention task (e.g., Eimer, 1996; Harter, Aine, & Schroeder, 1982; Hillyard & Münte, 1984; Mangun & Hillyard, 1988; Mangun & Buck, 1998), a participant sits in front of a computer monitor and is asked to pay covert attention to one of two locations (e.g., left or right) throughout an experimental block (i.e., sustain attention to the left or the right side of a computer's screen) while keeping eye-gaze on a central fixation. She needs to respond to visual targets randomly appearing at the attended and unattended locations as quickly and accurately as possible. To ensure that the participant pays more attention towards the attended location, the distribution of target stimuli is manipulated, so that targets are more likely to appear at the attended location (e.g., 75% of all trials; valid condition) than at the unattended location (e.g., 25% of all trials; invalid condition). Reaction times (RTs) are typically faster in the valid than the invalid trials. The RT difference between valid and invalid targets indicates also in this case the attention effect, a measure of behaviour benefit from attention allocation to the attended spatial location. The sustained attention task was mainly advocated by EEG researchers in order to avoid interference from cue-evoked potentials (e.g., that would occur with the Posner orienting task) in the target-relevant neural responses (e.g., Eimer, 1996; Harter, Aine, & Schroeder, 1982; Hillyard & Münte, 1984; Mangun & Hillyard, 1988; Mangun & Buck, 1998).

The sustained visuospatial attention paradigm plays a central role in the current thesis. As introduced above, the main aim of this PhD work was to investigate whether paying attention towards the same spatial location with another person modulates one's attention performance. In order to address this question, a modified (two-persons) version of the classic sustained attention paradigm was proposed (see the section "Dual attention paradigm" below for an introduction to the paradigm, and see Chapter 2 for detailed information about it). This dual attention paradigm was the core task employed along the current thesis.

1.2. Neural basis and electrophysiological correlates of visuospatial attention

This section overviews the literature regarding the neural basis and neural correlates of visuospatial attention. The role of the dorsal and ventral fronto-parietal attention networks in the control of endogenous and exogenous attention is described, as well as an overview of event-related potentials and brain oscillations research relevant to spatial attention orienting.

1.2.1 Dorsal and ventral fronto-parietal attention networks

Neuroimaging and neurophysiological research have robustly shown that visuospatial attention enhances neural activity in occipital and posterior parietal regions in a retinotopic and hierarchically organized manner (e.g., Di Russo, 2003; Di Russo & Pitzalis, 2014; Martínez et al., 2001), where the neuron's receptive field size (and complexity) widens progressively along the pathway towards higher-order visual areas (Felleman & Van Essen, 1991). However, although the neural expression of visuospatial attentional processing is related to the above-mentioned topographic modulations in occipital (and parieto-occipital) cortices, the implementation of the attention orienting mechanisms has been attributed to the interplay between two fronto-parietal systems: the dorsal and the ventral fronto-parietal networks (Chica, Bartolomeo, & Lupiáñez, 2013; Corbetta & Shulman, 2002; Vossel, Geng, & Fink, 2014). These networks have been associated with endogenous (voluntary or goal-driven) and exogenous (bottom-up or stimulus-driven) visuospatial attention, respectively (Corbetta & Shulman, 2002).

The dorsal and ventral fronto-parietal systems were first proposed and described in an influential review by Maurizio Corbetta and Gordon Shulman (Corbetta & Shulman, 2002). The dorsal network is organised bilaterally and includes the intraparietal sulcus (IPS), the superior parietal lobe (SPL), the anterior cingulate cortex (ACC) and frontal eye fields (FEF) in both hemispheres (Chica et al., 2013; Corbetta & Shulman, 2002; van den Heuvel & Hulshoff Pol, 2010). Neuroimaging studies have shown that activity in this network is enhanced (e.g., stronger blood oxygenation level dependent responses) by the voluntary deployment of attention towards a spatial location where a target is expected. This enhanced activation occurs contralaterally to the attended visual hemifield (Chica et al., 2013; Corbetta & Shulman, 2002; Vossel et al., 2014). For this reason, the dorsal network has been linked to top-down/endogenous control on visual processing and attentional orienting (Corbetta & Shulman, 2002). Contrary to the dorsal network, the ventral network is not activated by endogenous expectations. Instead, stronger activations in the ventral network have been reported during exogenous reorienting of attention towards unexpected visual targets (e.g., elicited by invalid cueing), causing an interruption in endogenous control (Chica et al., 2013; Corbetta & Shulman, 2002). The ventral fronto-parietal network is strongly right-lateralised, and comprises the temporo-parietal junction (TPJ), and the ventral frontal cortex (VFC), including parts of the anterior insula, the frontal operculum, the middle frontal frontal gyrus (MFG) and the inferior frontal gyrus (IFG) (Chica et al., 2013; Corbetta & Shulman, 2002; de Schotten et al., 2011; Vossel et al., 2014). Importantly, transcranial magnetic stimulation research (TMS) has provided valuable evidence in support of the causal role played by these fronto-parietal networks in endogenous (i.e., the dorsal network) and exogenous (i.e., the ventral network) visuospatial attention (e.g., Bourgeois, Chica, Valero-Cabré, & Bartolomeo, 2013; Capotosto, Babiloni, Romani, & Corbetta, 2012; Capotosto, Corbetta, Romani, & Babiloni, 2012).

A description of the fiber-tracts system thought to provide the structural connectivity underlying visuospatial attention has been provided as well. The superior longitudinal fascicle (SLF) has been suggested as the main structural system proportioning this connectivity (Chica et al., 2013; de Schotten et al., 2011). The SLF I projections overlap with the dorsal fronto-parietal network activations behind spatial orienting (e.g., IPS and FEF show strong connections along these fiber tracts). The SLF III on the other hand, overlaps with the ventral network activations in exogenous attention (e.g., connecting VFC and TPJ). In addition, the SLF II shows overlaps with the prefrontal part of the dorsal network and with the posterior section of the ventral network. Therefore, SLF II seems to provide the structural/anatomical means for communication between the two fronto-parietal networks. Indeed, it has been suggested that SLF II could interfere with the dorsal attention network, using information about salient events “spotted” by the SLF III to modulate or re-direct the goal-driven attention linked to SLF I (Chica et al., 2013; de Schotten et al., 2011).

1.2.2 Event-related potentials research

Event-related potentials (ERPs) research in visual attention has shown reliable modulations by attention in both sensory level components (e.g., P1 and N1), and in late higher-order event-related responses (e.g., N2b and P3). The P1 component is a positive deflection, typically picking around 100ms, and originated in the extrastriate cortex (Hillyard & Picton, 1987). The N1 on the other hand, is a negative deflection around 150-200ms, related to activity in the multiple neural structures (Clark, Fan, & Hillyard, 1994; Heinze, Luck, Mangun, & Hillyard, 1990). Both the P1 and N1 amplitudes have been consistently shown to be modulated by the voluntary visuospatial orienting of attention (e.g., Hillyard, Vogel, & Luck, 1998; Van Vorhis & Hillyard 1977; Vogel & Luck, 2000). In particular, in sustained attention experiments, where participants are asked to fixate the centre of the screen while focusing their attention to one particular location, enhanced P1s and N1s are obtained for stimuli appearing at the attended locations compared to the unattended ones (e.g., Luck, Woodman, & Vogel, 2000; Mangun, Hillyard, & Luck, 1993). These components however, do reflect different aspects of early sensory processes. P1 has been linked to the processing of physical properties of stimuli (Hillyard & Picton, 1987), and to a suppression mechanism for non-attended locations (e.g., Hillyard, Vogel, & Luck, 1998; Mangun & Hillyard, 1991), while the N1 has been associated with enhanced discrimination processing at the attended locations (Vogel & Luck, 2000; see also Mangun, 1995; Hillyard et al., 1998). These components are also modulated by the perceptual load level of the task at hand (i.e., enhanced amplitudes have been reported to increased perceptual loads), but do not necessarily respond in the same manner to variations in load (i.e., depending on the load level P1 may change and N1 remain unaffected, or viceversa), suggesting that they reflect different processing capacity limits in the brain (Handy & Mangun, 2000; Handy et al., 2001).

Another ERP component modulated by visual attention is the N2b (or anterior N2). Peaking around 200-350ms after the stimulus onset, and known to be originated in the medial prefrontal cortex (mPFC), particularly in the anterior cingulate cortex (ACC) (Crottaz-Herbette & Menon, 2006; Van Veen & Carter, 2002), the N2b component has been considered a marker of cognitive control (see Folstein & Van Petten, 2007 for a review; see also Vuillier, Bryce, Szücs, & Whitebread, 2016). In this line, this ERP component typically measured at fronto-central sites, is larger when inhibiting prepotent responses is required (i.e. response inhibition; see Folstein & Van

Petten, 2008). For instance, the larger N2bs are obtained for incompatible than compatible trials in cognitive control tasks (Folstein & Van Petten, 2007; Larson, Clayson, & Clawson, 2014; Van Veen & Carter, 2002), and enhanced N2bs have been found for no-go trials in go/nogo tasks (Jodo & Kayama, 1992; Pfefferbaum, Ford, Weller, & Kopell, 1985). This no-go N2 has been further shown to be enhanced when the no-go stimuli share target features, inducing a response that needs to be suppressed (e.g., Azizian, Freitas, Parvaz, & Squires, 2006). As for the P1 and N1 components, larger N2b amplitudes are usually obtained in response to attended stimuli (e.g., Eimer, 1993; see also Wei, Rushby, & De Blasio, 2019).

Attention related amplitude enhancements are also observed in P3 (or P3b) (Mangun, 1995; see also Luck, 2014), a positive deflection around 300-400ms. P3 however, is a functionally very heterogeneous event-related potential, and despite the vast amount of experiments published in relation to this component, no consensus has been achieved regarding the cognitive/neural processes associated to it (Luck, 2014). P3 has been associated (among others) with perceptual interference and action-related stimulus evaluation (Kok, 2001; Mangun, 1995; Polich & Kok, 1995; Zhou, Zhang, Tan, & Han, 2004; see Luck, 2014; Polich, 2012 for reviews), and has been considered as a measure of processing capacity and mental workload (e.g., Kok, 2001).

1.2.3 Alpha band oscillations

Almost a century ago, Hans Berger first observed and defined the alpha rhythm (Berger, 1929), the first electrophysiological signal recorded in the human brain. The initial observations showed parieto-occipital oscillatory patterns that were attenuated by opening the eyes, and reduced by attentive states (Adrian & Matthews, 1934a, 1934b; Berger, 1929). These observations were initially taken to suggest that alpha oscillations represented an ‘idling’ rhythm of the brain (Adrian & Matthews, 1934b). More recent research however, has shown that alpha oscillations actively contribute to human brain function, as an inhibitory rhythm (see Lopes da Silva, 2013 for a review). According to this view, alpha oscillations are considered as a marker of cortical inhibition (Klimesch, Sauseng, & Hanslmayr, 2007; Palva & Palva, 2007; Pfurtscheller, 2003; Ray & Cole, 1985; Sauseng et al., 2005; Thut, 2006), and a decrease in their amplitude has been linked to increased cortical activation or cortical excitability (Palva & Palva, 2007; Pfurtscheller, 2001).

Alpha oscillations have been widely studied in relation to visuospatial attention, and are known to covary with visual attentional changes (see Clayton, Yeung, & Cohen Kadosh, 2018). In visual attention tasks, an alpha suppression (i.e., a reduction in the amplitude/power of the oscillatory activity) in parieto-occipital areas is obtained in response to visual targets (e.g., Bauer, Stenner, Friston, & Dolan, 2014; Fan et al., 2007), or in the preparation period prior to their appearance (e.g., Kelly, Lalor, Reilly, & Foxe, 2006; Sauseng et al., 2005; Thut, 2006). This suppression is typically stronger in regions contralateral than ipsilateral to the attended visual hemifield (Sauseng et al., 2005). Following the cortical inhibition framework, the reduced contralateral alpha is thought to reflect a release of the cortical inhibition (or enhanced cortical excitability) in visual areas that would actively process the attended spatial locations, facilitating the subsequent cortical handling of visual inputs (Sauseng et al., 2005). The increased alpha amplitude at ipsilateral locations on the other hand, has been associated to an enhanced inhibition of cortical regions processing task-irrelevant information present in the ipsilateral hemifield (Kelly et al., 2006; Worden, Foxe, Wang, & Simpson, 2000).

The debate is still open regarding the origins of these oscillations in the human brain. Although no final consensus has been achieved in relation to the generators of this rhythm, current views point towards both thalamic and cortical contributions (Halgren et al., 2019). The calcarine fissure, secondary visual areas, and the parietal cortex have been shown to be involved in the generation of posterior alpha oscillations related to visual attention (Chapman, Ilmoniemi, Barbanera, & Romani, 1984; Ciulla & Takeda, 1999; Thut, 2006). However, rhythms in the same frequency range have been identified in several cortical regions, and linked to multiple processes beyond the visual domain (see Clayton et al., 2018 for a review; see also Sadaghiani & Kleinschmidt, 2016).

Furthermore, alpha band oscillations seem to support not only local attentional processing, but also information exchange across regions in the brain (Fries, 2015; Halgren et al., 2019; Patten, Rennie, Robinson, & Gong, 2012; von Stein & Sarnthein, 2000). Indeed, these oscillations have been linked to top-down processing, deemed as a top-down rhythm (Benedek, Bergner, Könen, Fink, & Neubauer, 2011; Doesburg, Bedo, & Ward, 2016; Halgren et al., 2019; von Stein, Chiang, & Konig, 2000), and may be closely related to cognitive control networks in order to implement inhibitory control (e.g., through a widespread increase in alpha power), facilitate local information processing (e.g., through focal alpha desynchronisation), and regulate long-range information exchange (e.g., by changing alpha band phase-locking between distant regions) (see Sadaghiani & Kleinschmidt, 2016). In the case of visuospatial attention research, it has been shown that the typically stronger alpha power reduction measured at posterior regions contralateral vs. ipsilateral (to the attended stimulus or hemifield) is usually accompanied by a stronger phase coupling between pre-frontal regions and the contralateral posterior sites than to the ipsilateral ones, suggesting a potential top-down influence from pre-frontal areas in the control of visual attention (e.g., Sauseng et al., 2005).

1.3. Joint performance

Research in the social cognition/neuroscience field has been developed employing two main approaches: studying either isolated or interacting minds (Chatel-Goldman, Schwartz, Jutten, & Congedo, 2013). A large amount of research is based on experiments involving participants performing tasks in isolation, as spectators in controlled environments, and responding to very well controlled stimuli. While these experiments have provided valuable knowledge about several social related processes (and their underlying neural correlates), it has been questioned whether these would actually represent how the human brain performs in complex, fast, dynamic, multi-agent scenarios, as real-life social interactions (Hari, Henriksson, Malinen, & Parkkonen, 2015). This section overviews a middle-ground approach between these two, by introducing several research findings where “interacting minds” jointly performed well controlled lab-based tasks, and describing the insights by them provided on the understanding of interpersonal influences in cognitive processes.

Before addressing the joint performance literature however, it is important to refer to early studies that analysed interpersonal influences under the paradigms of social facilitation (Allport, 1924) and social loafing (Latané, Williams, & Harkins, 1979). The initial results in the social facilitation literature indicated that when others are merely present, our performance could be either enhanced or impaired (e.g. Allport, 1924; Hunt & Hillery, 1973; Tripilett, 1898). Zajonc (1965) explained these findings by arguing that the presence of others induces an increased drive or arousal that modulates performance depending on the task complexity. In particular, according to Zajonc, dominant well learned actions result facilitated while non-dominant complex ones would be impaired. Alternatively however, it has been argued that the social facilitation effect could be elicited by social comparison with others (e.g., driven by the effort people make to present themselves as more competent, or by fear of evaluation and disapproval), or by fluctuations in cognitive capacity due to the presence of distracting others (e.g., distraction could create a stressful attention conflict eliciting the above-mentioned increase in drive/arousal) (see Guerin, 1993 for a review about social facilitation theories; see also Aiello & Douthitt, 2001). Social-loafing instead, refers to the reduced effort put into achieving a goal when working with others than alone (Latané, Williams, & Harkins, 1979). Social-loafing effects are usually obtained in groups when one expects other participants in the group to put the effort necessary to complete (or perform better) the task at hand, or when one's contribution cannot be tracked and identified by the rest (Karau & Williams, 1993). Both social facilitation and social-loafing provided the first insights (and a starting point) into examining socially driven modulations of human cognition. However, the idea that one's performance is changed due to the mere presence of other individuals, and that one's effort may be reduced when working with others, are still very basic in relation to the complex and dynamic nature of the social world.

More recently, several paradigms have been adapted in order to study the interpersonal influence on jointly performing individuals (e.g., joint Flanker task:Atmaca, Sebanz, & Knoblich, 2011; joint Spatial-numerical association response codes - SNARC: Atmaca, Sebanz, Prinz, & Knoblich, 2008; joint Simon task: Sebanz, Knoblich, & Prinz, 2003). Joint action is the most established research topic within the joint performance literature. Therefore, even though the current thesis did not examine joint action itself, relevant insights from this field will be here described. The Simon task (Simon & Rudell, 1967) in particular, has been intensively used in joint action research. In a standard Simon setting, participants respond to non-spatial stimulus features (e.g., the shape or colour of visual stimuli, or the auditory pitch of a tone) with actions that can be spatially compatible or incompatible to the spatial location of the stimuli (e.g., a left response for a stimulus presented on the left side or a left response for a stimulus on the right, respectively). Responses are faster in the compatible condition than in the incompatible condition (aka., Simon effect; Simon & Rudell, 1967). This is generally believed to reflect the conflict between spatial information processing and response selection in the spatial dimension (see Lu & Proctor, 1995 for an overview of different accounts). According to the dimensional overlap model (Kornblum, Hasbroucq, & Osman, 1990), there is an overlap between the irrelevant dimension of the stimulus location and the relevant response location. This overlap elicits an automatic activation of the response corresponding to the stimulus location. This leads to the faster RTs when the activated response matches the actual one (see also De Jong, Liang, & Lauber, 1994). From a Theory of Event Coding perspective (TEC; Hommel, Müsseler, Aschersleben, & Prinz, 2001), the effect could be explained by the binding between stimulus-response features and the subsequent match/miss-match between spatial stimulus and response codes (e.g., Hommel, 1993; Hommel, Müsseler, Aschersleben, & Prinz, 2001). It has been also proposed that attentional shifts prime responses, facilitating the corresponding ones, but slowing the non-congruent counterparts (e.g., Nicoletti & Umiltà, 1994).

Although the Simon Effect (SE) is present when participants perform the standard Simon task (i.e., responding to both stimuli using two response buttons), it disappears when people only perform half of the task (i.e., responding to only one of the stimuli using only one response button). This turns a choice-response task to a go/no-go task. In the go/no-go task, despite that the stimuli can be presented at a spatially compatible or spatially incompatible location, no SE will be observed because no response selection is needed, thus no stimulus-response conflict in the spatial dimension will occur (Hommel, 1996). However, the SE re-appears when the Simon task is shared between two participants. In this case, the participants (the co-actors) perform two slightly different go/no-go tasks, which are complementary halves of the standard Simon task (see Sebanz, Knoblich, & Prinz, 2003), and their performance is comparable to that when a single person carries out the standard Simon task. This social context of individuals performing jointly made researchers terming this effect joint Simon effect (JSE) (or social Simon effect, SSE) (Sebanz et al., 2003). Following this outcome, it has been proposed that people represent a co-actor´s actions (Sebanz et al., 2003) or tasks (Sebanz, Knoblich, & Prinz, 2005) as one´s own. This action or task co-representation in turn leads to an effect equivalent to the SE found in persons performing the standard Simon task alone (Sebanz et al., 2003, 2005). Moreover, this action/task co-representation is further considered to be a dedicated and automatic social process evidencing the social nature of perception and action (Knoblich & Sebanz, 2006; See Sebanz & Knoblich, 2009 for a review).

The social nature of the JSE however, has not gone unchallened (e.g., Dolk et al.,2013; Guagnano, Rusconi, & Umiltà, 2010; Lien, Pedersen & Proctor, 2016). In a series of five experiments, Dolk et al.'s (2013) found that the JSE can occur when participants act alongside non-human objects (e.g., a Japanese waving cat). Based on this evidence, Dolk et al.'s (2013) proposed a referential coding hypothesis to explain the JSE. This hypothesis makes use of the ideas expressed in the theory of event coding (TEC; Hommel et al., 2001), which aims to explain how events (i.e., perceived stimulus and generated responses/actions) are cognitively represented and how the interaction among these representations engenders perception and action (Hommel, 2009). Particularly for the TEC, self-generated events and those generated by others (including social or non-social events produced by living things or objects) are represented by the same codes (Dolk et al., 2014; Hommel, 2011;). So, employing TEC's ideas, the referential coding account proposes that the Joint Simon effect is generated by the need to solve a conflict generated by simultaneously active event representations; participants need to discriminate between task-relevant and task-irrelevant activations by focusing on the features that make it easier to differentiate among the co-active representations. This feature in the Simon task is usually the horizontal response location. Then, participants tend to code their own responses as "left" or "right", which generates the classical stimulus-response compatibility effect characterizing the SE (Dolk et al., 2011, 2013, 2014). Importantly, according to the referential coding account, any sufficiently active representation generated by an attended or salient event can create the described conflict (Dolk et al., 2013, 2014).

Even though the social nature in the Joint/Social Simon effect has been questioned (as introduced in the paragraph above; see Dolk et al., 2014 for a review), several findings have shown that the JSE is influenced by social factors. For instance, it is modulated by the type of relationship between co-actors (Hommel, Colzato, & van den Wildenberg, 2009), being present if co-acting with a friendly confederate, but absent if involved in a negative relationship with her. The primed social self-constructal has been shown to play a modulating role as well; a greater task co-representation was obtained when priming participants into an interdependent self-concept than when priming them into an independent one (Colzato, de Bruijn, & Hommel, 2012a). Enhanced JSEs have been also obtained among Buddhist co-actors compared to atheist ones, suggesting an influence from religious orientation and self-other integration (Colzato et al., 2012b). Moreover, evidence indicating an influence from social categorization factors, such as group-membership (Muller et al., 2011b; McClung, Jentzsch, & Reicher, 2013) and social status (Aquino et al., 2015) have been reported as well. In particular, the JSE has been obtained when co-acting with in-group members but not when paired with out-group co-actors (e.g., Muller et al., 2011b), independently on whether participants were involved in high or low competition conditions (McClung, Jentzsch, & Reicher, 2013), or when paired with a high-status in-group participant, but not when the co-actor was a low-status out-group member (Aquino et al., 2015). This social nature was also evidenced in a study showing that the JSE was present when one believed to be acting with a human, but not when the person believed to be co-acting with a computer (Tsai et al., 2008). Similarly, the JSE was present when a person was co-acting with a virtual human hand but not with a virtual wooden hand (Tsai & Brass, 2007), unless the non-human actor was believed to be acting intentionally (Stenzel et al., 2012) or its perspective could be taken (Muller et al., 2011a). All these constitute clear examples of cognitive processes being shaped by social context in joint action settings.

1.4. Attention in dyads: joint attention and shared attention research

Even when people are not explicitly performing actions together, they continuously keep track of other's attentional focus. Overt shifts in attention (i.e., eye movements and head turns) following another person's gaze have been intensively investigated in infants (see Mundy & Newell, 2007). It has been shown that since the first year of life, humans are able to follow other's gaze and to jointly attend to the same physical objects with them (aka. joint attention; see Frischen, Bayliss, & Tipper, 2007; Mundy & Newell, 2007), which is considered to be one of the most important skills in human social cognition, since it allows us to share, coordinate and cooperate with others (Mundy & Newell, 2007; Tomasello, Carpenter, Call, Behne, & Moll, 2005). In the lab, gaze-triggered attention shifts have been typically examined with a gaze-cuing paradigm (e.g., Friesen & Kingstone, 1998). In this task, participants are presented with a central picture or schematic drawing of a face that gazes to different locations (e.g., left or right). Participants are asked to detect or discriminate targets appearing either at the cued location or at the opposite one, echoing the standard attentional cueing task introduced earlier (e.g., Posner, 1980). When the targets appear at the previously gaze-cued location, responses are faster than when they appear at an uncued location. This effect is consistently present, even when the gaze-cues do not predict (or are counter-predictive) of the target locations and are therefore non informative (or disadvantageous/harmful) for completing the task at hand (e.g., Friesen & Kingstone, 1998; Friesen, Ristic, & Kingstone, 2004). In other words, this effect occurs in an involuntary/automatic manner (see the section "visuospatial attention" above). Although the reasons underlying these effect are still being debated (e.g., Kingstone, Kachkovski, Vasilyev, Kuk, & Welsh, 2019; Wiese, Wykowska, Zwickel, & Müller, 2012; see also Gobel, Tufft, & Richardson, 2018), the attention shifts elicited by gaze-cues are quite reliable, and their robustness has not been questioned. Importantly for the present PhD work however, the investigation in the joint attention field has been mostly focused on its relation to cooperation, bonding, theory of mind, and social learning (Mundy & Newell, 2007; Siposova & Carpenter, 2019; Tomasello et al., 2005; Tomasello et al., 2012), without consideration for the specific role of the attended spatial locations and its relation to attention performance.

Beyond the advantages of attention coordination provided by gaze following, it has been proposed that the human mind may give some preference to those stimuli in the environment that are attended together with others (i.e. Shared attention theory; Shteynberg, 2015), simply by the knowledge that they are being co-attended, even in the absence of interpersonal behavioural observation (i.e., without observing the other's attentional focus or following their gaze). According to Shteynberg (2014, p.1), "mental processes can be inherently social, with sociality 'baked into' the architecture of the cognitive mechanism". In this line, it could be possible that the human mind, having a limited processing capability, would give some preference to those stimuli in the environment that are attended together with others (i.e. shared attention theory; Shteynberg, 2015). Indeed, Shteynberg and colleagues have suggested that sharing attention towards the same objects or tasks could cause more cognitive resources being allocated to these objects or tasks, resulting in better performance in general (Shteynberg, 2015). The gathered empirical evidence suggests that memory (Shteynberg, 2010), motivation (Shteynberg & Galinsky, 2011), judgement (Shteynberg, Hirsh, Galinsky, & Knight, 2014), emotion (Shteynberg, Hirsh, Apfelbaum, et al., 2014), and behavioural learning (Shteynberg & Apfelbaum, 2013) may be affected (Shteynberg, 2015). For instance, when presenting participants with a list of words believed to be co-attended with similar vs. different others, recall was both faster and more accurate in the former scenario (Shteynberg, 2010). Thus, shared attention may make the jointly attended objects/events more cognitively accessible and easier to recall (Shteynberg, 2010). Similarly, it has been suggested that the "shared attention state", would increase the influence of mood on evaluative judgements making them more extreme, induce more intense emotional reactions to the co-attended objects, boost individual goal pursuit for co-attended goals, and intensify imitation, favouring social learning. Importantly, according to Stheynberg's theory, this shared attention is a psychological state that implies the activation of a collective perspective when experiencing the world with others (Shteynberg, 2015, 2018). Sharing attention with others under this definition activates a "we mode" in which one's perspective is also the other person’s perspective, it becomes a collective one. This “we-mode” however, and the cognitive enhancement induced by it, would only occur if people believe that they are simultaneously co-attending with similar others (i.e. members of the same group) (Shteynberg, 2014, 2015). Importantly, as in joint attention-related research, the specific role of the attended spatial locations and its relation to attention performance has not been considered by the shared attention field.

At this point, it is necessary to make some clarifications regarding several definitions used in literature (and in this thesis) that could otherwise turn out quite confusing. I will refer particularly to the definitions of joint attention, social attention, and shared attention. Joint attention for instance, has been a quite popular, but independent, area of research in both psychology and philosophy, and therefore, many definitions have been proposed (see Milward & Carpenter, 2018; Siposova & Carpenter, 2019 about the current joint attention definition debate). In a simple way, joint attention could be defined as "looking where others are looking” (Butterworth, 1995, p. 29). A more accepted version however**,** was proposed by Tomasello, Carpenter, Call, Behne, and Moll (2005). According to this definition, besides looking where others are looking, it is necessary that the individuals know that they are looking together to the same jointly attended object (Tomasello, Carpenter, Call, Behne, & Moll, 2005 ; see also Frischen, Bayliss, & Tipper, 2007; Mundy & Newell, 2007)**.** In a similar line, social attention has been defined as “the cognitive process that underlies gazing at or with another person” (Richardson & Gobel, 2015, p. 350). The overlap between the two definitions (i.e., social vs. joint attention) is evident. In this thesis I will treat them as analogue/equivalent, and I will use them to refer to gaze following/looking where others are looking. Shared attention on the other hand, has been proposed as a psychological state that implies the activation of a collective perspective when experiencing the world with others (Shteynberg, 2015, 2018). Sharing attention with others under this definition activates a “we mode” in which one’s perspective is also the other person’s perspective, it becomes a collective one. If considered in the situation where we are looking/attending to the same object with another person, it may seem that the definitions of joint attention and shared attention are equivalent. They are however, essentially different. While joint attention has its roots on behavioural observation (i.e., observing other’s looking/gazing behaviour), shared attention is a psychological state (“we-mode”) that does not require observing others. In this psychological state, the other co-attendees are not social inputs, but part of the cognitive mechanism itself (Shteynberg, 2018)**.**

Analogue to Stheynberg's research, Richardson et al. (2012) examined the changes that could be elicited on participants attention to images, by the knowledge that others are encountering the same sort of stimuli simultaneously (aka. Joint Perception; Richardson et al., 2012). To this aim, Richardson et al. (Exp1), tracked participants' eye gaze while they watched a set of images with different valence. Participants were told either that a person in the other side of the room was doing exactly the same thing, or that they were watching the images alone while the other person was looking at some symbols. There was no interaction between participants and they had no access to what or where the other person was actually looking at. Interestingly, under this social context, when participants thought their partner was looking at the same set of images, they looked significantly more at the images with negative valence. This belief seems to influence not only eye movements, but also memory processes (Exp 2). Importantly however, for this joint perception effect to take place, it is necessary not only to belief that the other is experiencing the same stimuli, but that he/she is doing the same task (Exp 3). Richardson and colleagues considered four different possible explanations to their findings. They considered possible (but unlikely) that the minimal social context provided by the experiment could have enhanced a pre-existing negativity bias (evolutionary driven to facilitate threat detection; Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001) due to a greater feeling of threat during the experiment. Alternatively, it was argued that the minimal social context could have increased participant's alertness, inducing social facilitation effects. Yet, as pointed out by the authors, there was no increase in the looking times towards the positive images, reducing the plausibility of this argument. Moreover, Richardson and colleagues considered the possibility that this joint perception context may have induced a feeling of cooperation that increased the emotional alignment towards the negative images, or that maybe participants simply looked for those images that would be more salient for their partners (i.e., in this case, the negative images, given the link between saliency and valence in their experiment). In any case, this minimal social context modulated participants attention behaviour, adding to the literature suggesting a pervading influence of social context on human cognition (Richardson et al., 2012).

Although these results might seem similar to those obtained in Shteynberg´s (2010, 2015) studies, they differ importantly. As a reminder, the shared attention theory posits that the sole knowledge that other individuals are co-attending to the same objects/tasks could cause more cognitive resources to be allocated to these objects/tasks, resulting in better performance in general (Shteynberg, 2015, 2018). In

Richardson et al.'s (2012) experiments instead, the attention allocation was shifted to specific images by the belief of attending the same stimuli simultaneously with an experiment partner. This occurred without any knowledge in relation to the other person's specific focus of attention (i.e., without knowing where exactly the other was looking at) (Richardson et al., 2012). This outcome could not be predicted based on the shared attention framework, and suggest an interpersonal influence in cognitive processing that goes beyond Shteynberg's proposals.

A few studies have reported interpersonally driven modulations in performance when completing attention-related tasks in dyads (Böckler, Knoblich, & Sebanz, 2012; Gobel, Kim, & Richardson, 2015; Gobel et al., 2018; He, Lever, & Humphreys, 2011; He et al., 2014; Welsh et al., 2005, 2007). It has been shown for instance, that the spatial allocation of visual attention in a visual search display can be guided by the knowledge about the contents in a co-actor's working memory (aka. interpersonal memory guidance of attention; He, Lever & Humphreys, 2011). Visual attention is known to be guided by stimuli held in working memory (WM) (Chelazzi et al. 1993), even when they are task-irrelevant. If participants perform a visual search task while keeping an item in WM, the visual search is altered if the memorized item re-appears in the search display (e.g. Downing 2000). He, Lever, and Humphreys (2011) modified this paradigm, so it could be performed by two participants sitting alongside each other. Each participant had to hold in WM an item from a specific category (three categories were available, one per participant and one that none of them had to memorize -the baseline) and then performed a visual search task (searching for shapes). The item held in WM could re-appear in the visual search, either in a valid (same as the target) or invalid location. There was not only an "own memory effect" on attention (faster RTs for the items in the own category re-appearing in valid locations on the subsequent visual search, than those appearing in invalid locations), but also an effect when the items re-appearing were those in the co-actor's category. He and colleagues concluded that when involved in the same task, participants may code/represent information in the co-actors WM, and this information could guide visual attention interpersonally. This interaction between working memory and attention however, is specific for situations of attention deployment while maintaining memory contents, therefore may not be able to reveal an interpersonal influence utterly related to attentional mechanisms.

A more specific view into attentional modulations in dyadic tasks was proposed by Böckler, Knoblich and Sebanz (2012). In their study, Böckler, Knoblich and Sebanz

(2012) employed a dyadic version of the Navon task to study task co-representation in attentional settings. In the single person version of the Navon task (Navon, 1977), participants are presented with a large letter (global stimulus feature) formed by many small letters (local stimulus feature). Their task is to discriminate/identify one of the two (i.e., either the local or the global feature of the stimuli). Faster responses are usually performed to the global compared with the local stimulus features. Moreover, regardless of the focus of attention (local or global), responses are typically impaired/slowed down when these features are incongruent (e.g., attending to the global feature when the stimuli is a large letter H formed by small letters Ss), compared to the congruent condition (e.g., attending to the global feature when the stimuli is a large letter H formed by small letters Hs). In the two-persons version of this task proposed by Böckler, Knoblich and Sebanz, participants still respond to the identity of the letters, but they are either focusing on the same (e.g., both people attending to the local stimulus features) or different (e.g., one person attending to the local feature, and the other person focusing on the global feature of the stimulus) aspects of the task. In this dyadic setting, participants were slower at responding when the co-actor had a different focus of attention, suggesting that the different attentional focus employed by (or instructed to) the co-actor interfered with ones own focus when performing the task (Böckler, Knoblich, & Sebanz, 2012).

Although a co-actor with a different focus of attention impairs one's performance in the joint Navon task, it has been shown that the availability of information about a co-actor's task/actions and/or performance can be greatly advantageous when sharing/collaborating in visuospatial tasks. Brennan, Chen, Dickinson, Neider, and Zelinsky (2008) instructed pairs of participants to perform a collaborative visual search task (i.e., searching for an O-in-Qs), while allowing them to either talk to each other to communicate their search strategies (shared speech condition), or have access to the task partner's gaze during the task as measured by an eyetracker (shared gaze condition), or both (shared gaze and speech condition). A better performance was always achieved for the collaborative conditions compared to a solo-version of the task. The best performance however, was not achieved when both speech and gaze were shared, but when only information about the co-actor's gaze behaviour was available (see also Wahn, Kingstone & König, 2017). This suggests that shared gaze is a very efficient way of mediating collaboration in visuospatial tasks, even beyond the advantages provided by direct communication through spoken words.

Additional evidence suggest that even very basic and robust attention orienting mechanism may be modulated by social context. The Inhibition of return (IOR) is a slowing of responses to targets presented at previously attended locations resulting from an inhibitory mechanism keeping attention away from previously attended events/locations (Klein, 1990, 2000; Klein & Taylor, 1994; Lupiáñez, Klein, & Bartolomeo, 2006; Posner, Rafal, Choate, & Vaughan, 1985). It has been shown that this robust attention orienting effect is also present when responding to locations previously attended by another person (Gobel et al., 2018; Tufft, Gobel, & Richardson, 2015; Welsh et al., 2005, 2007). Welsh et al. (2005, 2007), found evidence for this joint/social IOR from dyads of participants sat opposite to each other performing reaching arm movements towards targets in a turn-taking manner. Participants were slower when reaching to locations previously touched by the task-partner (social / between-person IOR), an effect that is typically obtained when reaching for one's previously touched/attended locations (classic /within-person IOR). The researchers proposed the mirror neuron system as a mediating mechanism. In this line, they suggested that the activation of the mirror neuron system when observing the co-actor's actions may simulate their responses, generating the same kind of inhibitory mechanism behind the single person IOR (Welsh et al., 2007). An alternative account questioning the socialness of this effect suggests that the motion of the partner's arm could cue/induce an attentional shift in the observer, as any other salient event would do, generating/producing the "social" IOR effect (Cole, Skarratt, & Billing, 2012). Nonetheless, additional evidence for a social account/origin of this effect came from a classical cued IOR / spatial orienting paradigm where the social relevance of the cues was manipulated (Gobel et al., 2018). In a series of two experiments, Gobel et al. (2018) manipulated participants' beliefs regarding the origin of the cues during this classical IOR task. Participants were told that the cues were either randomly generated by a computer (non-social condition), or that they indicated the gaze behaviour of a second person (social condition) sat back-to-back with the participant (Exp1). Although the cues were always randomly generated, when the participants believed that the cues reflected the gaze position of the other person, they showed larger IORs compared to the non-social condition. A second experiment extended this finding by showing that the effect is modulated by the social hierarchy attributed to the co-actor. The effect was stronger when the cue was believed to indicate the gaze of a higher social rank/status individual. This however, only occurred when the experiment partner was believed to be engaged in the same task (i.e., not when they were believed to be performing an unrelated memory task), echoing previous findings related to the shared attention theory by Shteynberg (2015).

Taken together, Gobel et al., experiments showed that not only the physical saliency of the cues, but also their social relevance (“whether the cue is connected to another person, who this person is, and what this person is doing”, as defined by Gobel et al., 2018) matter in spatial orienting. This also represented the first reported evidence showing that basic cognitive processes can be interpersonally modulated by social context (see also Tufft, Gobel, & Richardson, 2015). However, this investigation was performed exclusively on the inhibition of return (IOR). Considering that different attentional processes are thought to be relatively independent or not interrelated in terms of the underlying mechanisms (e.g., Pan, Wu, & Zhang, 2017; Slessor et al., 2019), further research is needed to examine the extent to which social context and interpersonal influences modulate other basic attentional processes apart from the IOR.

1.5. Attention in dyads: Neural basis and electrophysiological correlates

This section overviews the literature on the neural basis and neural correlates behind co-attending to the world with other individuals. Given the overwhelming contribution of joint attention research in this regard, this overview is mainly based on joint attention related findings, including neuroimaging, event-related potentials, and brain oscillations research. A brief introduction to hyperscanning research (i.e., the simultaneous/synchronised measurement of brain activity from multiple subjects; Montague, 2002) is also provided.

1.5.1 Neural basis of joint/shared attention

Joint attention interactions involve one person directing another person’s attention towards an object, event or location (IJA, Initiating Joint Attention), and the other person following the first one (RJA, Responding to Joint Attention). It constitutes a complex process in which the interacting individuals need to detect and monitor the other’s gaze, encode the gaze/head direction, and (re-)orient visual attention accordingly, while considering self and other’s related information, and their relation to the environment (see Emery, 2000; Frischen, Bayliss, & Tipper, 2007; Langton, Watt, &

Bruce, 2000; Nummenmaa & Calder, 2009 for reviews). Therefore, it shouldn't come to a surprise that this complex process is supported by widespread networks in the human brain (see Mundy, 2018 for a comprehensive review)

The Parallel and Distributed Processing Model of joint attention (PDPM; Mundy & Newell, 2007; Mundy, Sullivan, & Mastergeorge, 2009) has been the most influential model in the field. According to the PDPM, joint attention is an information processing system that processes (and integrates) in parallel internal information related to the self and one's visual attention, and external information related to other people and their visual attention (Mundy et al., 2009). This information processing system was proposed to be implemented by an interplay between the distributed anterior and posterior attention networks previously described by Posner (e.g., Posner & Rothbart, 2007; see Mundy & Newell, 2007; Mundy et al., 2009), with the posterior network more closely associated to RJA, and the anterior network supporting mainly IJA (Mundy et al., 2009). The posterior network includes the posterior superior temporal sulcus (pSTS), the precuneus, the occipital association cortex, the posterior parietal cortex, and the intraparietal sulcus, and has been implicated in the processing of spatial information, gaze/head perception, the discrimination of their orientation, and visual spatial orienting (Mundy et al., 2009). The anterior network on the other hand, is thought to assist the goal-directed control of attention towards rewarding stimuli, the suppression of automatic gaze shifts, and the representation of the joint action partner's perspective. This network comprises the medial prefrontal cortex, the anterior cingulate cortex, the frontal eye fields, the orbitofrontal cortex, as well as sections of the basal ganglia (Mundy et al., 2009).

Despite the challenges of investigating the neural basis of joint attention using MRI scanners (mainly in terms of balancing experimental control and the ecological validity of the paradigms employed; Schilbach et al., 2013, 2010), a few neuroimaging studies have provided support for the PDPM (e.g., Caruana, Brock, & Woolgar, 2015; Redcay, Kleiner, & Saxe, 2012). For instance, Redcay, Kleiner, and Saxe (2015) investigated the neural basis of IJA and RJA in a fMRI experiment with a dual video set-up. Participants in this experiment either cued the experimenter to look at a target (IJA), or were cued by the experimenter (RJA). Neural responses were contrasted to a baseline in which the participant shifted attention towards the target, but the experimenter had the eyes closed. Relative to this baseline, recruitment of the ventromedial prefrontal cortex was distinctively associated with RJA, and activity in the

the intra-parietal sulcus and middle frontal gyrus were related to IJA. Overlapping regions were also individuated. Indeed, the dorsomedial prefrontal cortex (dMPC) and the right posterior temporal sulcus (pSTS) showed common activation patterns for both IJA and RJA (Redcay, Kleiner, & Saxe, 2012). Similarly, by means of a cooperative virtual reality joint attention game, Caruana et al. (2015) showed that both IJA and RJA commonly activated frontoparietal networks comprising the middle and inferior frontal gyrus (MFG & IFG), the middle temporal gyrus (MTG), the posterior temporal sulcus (pSTS), the temporo-parietal junction (TPJ), and the precuneus. IJA on the other hand, specifically recruited the anterior and middle cingulate cortex, superior frontal gyrus, the thalamus and the cerebellum (Caruana, et al., 2015). These studies support the idea of a widespread but integrated system underlying the parallel processing required in joint attention.

Another influential study was provided by Schilbach and colleagues (Schilbach et al., 2010). Participants inside an MRI scanner engaged in joint attention with a virtual character "controlled by another person outside the scanner" (in reality the character was controlled by a gaze-contingent algorithm). In this joint attention interaction both IJA and RJA were contrasted against a baseline consisting in an incongruent gaze shift. That is, the IJA trials were identical to the IJA baseline trials, except that in the IJA baseline, the virtual character averted the gaze from the location attended by the participant. Similarly, the RJA baseline was created by instructing participants to make an incongruent gaze shift respect to the virtual character's. Compared to the baseline, RJA showed activity in the mPFC, a region that has been also related to mentalising processes (i.e., making inferences about other's beliefs or intentions) (Amodio & Frith, 2006; see also Frith & Frith, 2006; Van Overwalle, 2009; Williams et al., 2005). Moreover, IJA showed differential activations in reward-related areas (e.g., the ACC and the ventral striatum) (Schilbach et al., 2010; see also Gordon, et al., 2013; Pfeiffer et al., 2014 for additional studies showing a link between joint attention and reward's processing networks). Since the contrast in this case was computed between joint (or congruent) and dis-joint (or incongruent) attention conditions, the relative findings have been interpreted as suggesting a link between the evaluation/accomplishment of joint attention, and mentalising/social-reward processing in the brain (Schilbach et al., 2010; see also Mundy, 2018).

In a recent review (Mundy, 2018), Peter Mundy comprehensively integrated the literature on the neuroscience of joint attention (e.g., Brunetti et al., 2014; Caruana, Brock, et al., 2015; Gordon et al., 2013; Pfeiffer et al., 2014; Redcay et al., 2012; Schilbach et al., 2010; Williams et al., 2005). In this review, he identified a set of primary neural nodes comprising the joint attention system: the dorsal and medial frontal cortex, the orbitofrontal cortex and the insula, the anterior and posterior cingulate cortex, the superior temporal cortex, the precuneus and parietal cortex, and the amygdala and striatum. Hence, undoubtedly, joint attention has been shown to be a complex process supported by widespread networks in the human brain (see Mundy, 2018 for more details).

1.5.2 ERPs and brain oscillations

Early studies employing traditional gaze-cueing paradigms reported enhanced P1 and N1 event-related responses for valid (i.e., trials were the gaze shift predicted the target location), compared to invalid trials (i.e., trials were the target appeared at the opposite location indicated by the cue) (Schuller & Rossion, 2005; Schuller & Rossion, 2001, 2004; Tipper, Handy, Giesbrecht, & Kingstone, 2008), echoing typical findings in the visuospatial attentional orienting literature (described in the section “visuospatial attention” above). More recently, event-related responses have been examined using more elaborated social manipulations in relation to joint attention (e.g., (e.g., Böckler & Sebanz, 2012; Caruana, de Lissa, & McArthur, 2015, 2017; Caruana & McArthur, 2019; Wykowska, Wiese, Prosser, & Müller, 2014). In Wykowska, Wiese, Prosser, and Müller (2014), participants completed a typical gaze-cueing task with a centrally presented face of a humanoid robot. In this task, the robot was either gazing towards the location where a subsequent target would appear (valid trial), or the opposite (invalid trial). Participants were either told that the robot’s gaze was controlled by a human or by a computer. Under these conditions, participants ERP responses time-locked to the target onset were examined, revealing a stronger P1 amplitude for valid than invalid trials (and no effect in N1), but only when the robot’s gaze was believed to be controlled by a human. This was interpreted by the author’s as potentially suggesting that adopting (or not) an intentional stance towards the robot (i.e., assuming that it has a mind) top-down modulated the attentional control over the early sensory processes measured by P1 (i.e., sensory gain) (Wykowska et al., 2014).

Caruana and colleagues (Caruana, de Lissa, et al., 2015; Caruana et al., 2017; Caruana & McArthur, 2019) investigated the neural correlates of IJA. In their task, participants initiated joint attention to direct a virtual character’s gaze towards a target.

This character was believed to be controlled by a human in another room (Caruana, de Lissa, et al., 2015). The character followed the participant's joint attention bids 50% of the times (congruent condition), while ignoring it (averting gaze) for the rest of the trials (incongruent condition). Stronger centro-parietal P350 ERPs were obtained to incongruent gaze shifts, respect to the congruent ones (Caruana et al., 2015, 2017; Caruana & McArthur, 2019).The opposite effect was found in centro-parietal P250 (i.e., larger amplitudes for the congruent responses) (Caruana & McArthur, 2019). These modulation in P250 and P350 however, dissapeared when the virtual character's gaze was believed to be computer-controlled (Caruana et al., 2017; Caruana & McArthur, 2019). The authors suggested P250 and P350 reflected discrimination processing regarding the outcome of a joint attention bid (i.e., the success or evasion of joint attention), and that this process was only recruited when believes about human agency in relation to the "co-attending" virtual character were adopted (Caruana, de Lissa, & McArthur, 2017; Caruana & McArthur, 2019).

Moreover, when performing together responding to the identity of letters in a two-choice Navon task, with participants focusing either on the same or different aspects of the task (i.e., local vs. global features), Böckler and Sebanz, (2012b) obtained evidence showing a significant reduction in P1 and P3 amplitudes when the co-actor had a different focus of attention. They suggested this could be explained by a greater difficulty in selecting one's focus of attention when the co-actor's one differs, impairing early allocation of attention and increasing response monitoring. Additionally, an enhanced anterior N2 (or N2b) was found when the co-actor attended to the local vs. global features of the task, suggesting that the co-representation of the other's task could include details about his/her specific attentional focus (Böckler & Sebanz, 2012b).

The joint attention literature has also provided evidence for alpha band power modulations when comparing joint versus dis-joint attention conditions in spatial cueing like-paradigms (e.g., Hoehl et al., 2014; Michel et al., 2015; Rayson et al., 2019). For instance, research with infants has shown a greater suppression of alpha band activity when an adult (a picture of an adult's face) turned her gaze towards the attended object than when her gaze looked towards a different object (Rayson et al., 2019), or when looking to an object attended by another person compared to an averted gaze (i.e., they used a picture of a person gazing towards an object in the screen or averting gaze from the object) (Michel et al., 2015). Similarly, in Hoehl et al. (2014) babies showed a widespread alpha reduction when looking at the same object in the screen simultaneously with an adult (this time a real one) positioned next to the screen, but only when eye contact with the adult preceded joint attention. These findings posit alpha oscillations as a promising avenue to understand attention variations in social settings.

Although these studies have provided an initial insight into the neural underpinnings of human performance and cognition in social settings, further research is needed to understand the way cognitive processes are informed and modulated by social context. A shift towards studying two or more interacting individuals and measuring/examining their brain activities simultaneously has been encouraged in the last decade (see Hari et al., 2015; Hari & Kujala, 2009; Schilbach et al., 2013), promising to bring a revolution in the neuroscience field (Hasson et al., 2012). In this line, the following section introduces relevant research evidence and the derived insights that studying multiple brains simultaneously has brought to the understanding of joint/shared attention (see the *"Hyperscanning research"* section below).

1.5.3 Hyperscanning research

Hyperscanning refers to the simultaneous/synchronised measurement of brain activity from multiple subjects (Montague, 2002). The first multi-subject recordings were reported by Duane and Behrendt (1965) in an attempt to study extrasensory induction between identical twins using EEG. More recently the technique was "re-introduced" by Montague (2002), who demonstrated its feasibility using two inter-connected fMRI scanners. In the EEG community, the first studies (after Duanes and Behrendt's) were carried out by Fabio Babiloni and Laura Astolfi's group, investigating cooperation/competition in multiple subjects involved in game theory related tasks (Astolfi et al., 2011; Babiloni et al., 2006; see also Barraza et al., 2019 for a tutorial on EEG hyperscanning setups). Since then, the hyperscanning technique gained popularity and multiple studies have been reported employing synchronised EEG, MEG, fMRI and fNIRS measurements (aka. dual EEG/MEG/fMRI/fNIRS) to study different facets of social cognition (e.g., interpersonal coordination, social/joint/shared attention, coordinated movement, speech coordination, mental coordination, coordinated activities in social and ecological contexts, interactive decision-making, affective communication, etc (see Koike, Tanabe, & Sadato, 2015; Liu et al., 2018; Mu, Cerritos, & Khan, 2018; Wang et al., 2018; Zhang, 2018 for recent reviews).

In joint/shared attention research, the EEG hyperscanning technique has been employed to study multiple subjects simultaneously both in the lab and in more naturalistic scenarios (e.g., a classroom), providing some initial insights regarding potential oscillatory intra and inter-brain correlates of attending to the world with others. For instance, Lachat, Hugueville, Lemaréchal, Conty, and George, (2012) investigated the neural correlates of joint attention using an online joint attention paradigm, where participants (dyads) were either looking to the same or different LED lights placed in front of them, while simultaneous EEG was recorded. Joint attention was contrasted for both social (i.e., instructed driver vs. follower gaze behaviour) and externally driven conditions (i.e., participants instructed to follow a specific LED colour, either looking to the same or different one). Under this setting, oscillations in the 11-13Hz range over parieto-occipital (i.e., alpha rhythm) and centro-parietal (i.e., mu rhythm) areas were modulated by joint attention. In particular, a decrease in alpha and mu rhythms was obtained for the joint attention condition for both social and externally driven attention. The authors suggested mu-rhythm-related attention mirroring and alpha-rhythm-related arousal and visual attention mechanisms as the potential sources of these effects. More recently, Szymanski et al. (2017) examined dyads performing a joint visual search task while dual-EEG was recorded. In this task, participants had to indicate the number of targets present in a visual search display, while performing either individually or in teams. In the individual condition they completed the task from separate computers. In the joint condition, they shared the same visual search display and were allowed to use any strategy they could devise to complete the task as a team (they could talk, gesture, interact, etc., minimizing movements). The researchers found that both intra and inter-brain synchrony in the delta (2Hz) and alpha (8Hz) bands were significantly higher when the dyads completed the task jointly than when they performed individually, and that this synchrony positively correlated with team performance. The findings were interpreted as neural substrates of social facilitation (Szymanski et al., 2017). Furthermore, taking advantage of the portability of the EEG systems, Dikker et al. (2017) followed 12 students along 11 high school biology lessons, while simultaneously recording their brain activities using EEG headsets. They found that the students inter-brain synchrony not only predicted the students' engagement levels, but was also related to social dynamics (e.g., correlated with the teacher likeability and the pairwise students closeness). The authors proposed a joint attention account for these effects. In this account, the students' neural oscillations entrainment to the external stimuli is modulated by the stimuli themselves (e.g., the teacher or classroom videos) and the attention levels (Dikker et al., 2017). The entrainment would not occur (or would be quite low) under “low attention” states, reflected in low brain-to-brain synchrony. However, when in a high “shared attention” level/state, alpha oscillations would decrease (this was corroborated in their data) and become entrained or “tuned” to the the environment (i.e., to the temporal structure of the surroundings), increasing the synchrony between brains (Dikker et al., 2017). Leong et al. (2017) tested infant-adult dyads instead. In this study, infants looked at singing adults while the adult’s gaze-behaviour was manipulated (direct vs. indirect). EEG was recorded simultaneously from the dyad, and partial directed coherence (Baccalá & Sameshima, 2001) was employed to assess the dyad’s inter-brain connectivity. This connectivity measure allows conclusions regarding the direction of the connectivity estimates. The study showed that direct gaze enhanced the adult-infant brain-connectivity in both directions (i.e., adult to infant and viceversa). In addition, infants vocalized more during the direct gaze condition, and those who vocalized more also induced a stronger inter-brain synchrony in the dyad. The researchers suggested that the exchange of social signals (i.e., gaze and speech) might produce a phase reset in neural oscillations that temporally aligns the interacting brains, as reflected by the reported enhancement in their inter-brain connectivity.

Even though the new insights provided by the hyperscanning technique are certainly promising, it is important to mention that the physiological and psychological interpretation of the findings is not clear at the current stage, nor the origins of inter-brain synchronicity, or the factors influencing/modulating it (Burgess, 2013; Hari, Henriksson, Malinen, & Parkkonen, 2015). In addition, in order to get the most out of the hyperscanning technique/data, more real-life-like experimental paradigms need to be devised, and further developments are required from the analysis methods side (Burgess, 2013; Hari, Henriksson, Malinen, & Parkkonen, 2015).

1.6. The present PhD project

The previously reviewed theories and empirical findings suggest a pervasive influence from social context on human cognitive processes, including attention. According to these evidence, our (human) behaviour and performance is changed when others are around (social facilitation: Allport, 1924). Moreover, we might make representations of the others’ tasks/actions that could interfere or facilitate our own actions/tasks when co-acting with them, even if their actions/tasks are irrelevant for us (joint action co-representation: Knoblich & Sebanz, 2006). In addition, we constantly keep track of other's gaze to understand them and coordinate behaviourally (joint attention: Frischen, Bayliss, & Tipper, 2007), and our looking behaviour is altered just by knowing that we perceive the same stimuli with another person (joint perception: Richardson et al., 2012). Even more, it has been shown that the knowledge of the contents in a co-actor's working memory can interpersonally guide the spatial allocation of visual attention (interpersonal memory guidance of attention; He, Lever & Humphreys, 2011), and it has been proposed that our general cognitive performance may be enhanced just by knowing that we are attending the same objects or tasks with similar others (in-group members) (shared attention: Stheynberg., 2015). Although it becomes hard to question an influence from other humans around us (including their actions/tasks and the context of our interactions) on our cognitive processes, additional research is needed to understand how "deep" can this interpersonal influence affect our cognition, which factors modulate it, and the underlying brain processes. In this line, the purpose of the current PhD work was to investigate whether this interpersonal influence on cognition could permeate even basic attentional mechanisms. Gobel et al. (2015, 2018) provided evidence in this direction by showing that the social relevance attributed to visual cues can modulate spatial orienting. Even though this represented the first evidence for basic attentional mechanisms being modulated by social context, the evidence provided comes exclusively from examining the inhibition of return (IOR). Further research is needed to understand whether social context and interpersonal influences modulate additional attentional processes.

Accordingly, the present PhD research project aimed at contributing to the understanding of how interpersonal social influences and social context inform and shape human visual sustained attention in dyadic settings. Specifically, the work described in the following chapters attempts to answer the following questions:

- Does human visual attention act differently (i.e., attention performance is changed) when another person pays attention to the same location with us, in the absence of direct communication or explicit interactions (i.e.., without gaze following/coordination or a speech exchange), just by knowing that the locus of attention is shared, even if this knowledge is irrelevant/trivial for one's task/goals/performance?

- If so, which task components and/or social factors modulate this interpersonal influence?

- Finally, what are the neural correlates characterizing this interpersonal influence over human attention in dyadic settings?

Undoubtedly, obtaining evidence pointing towards interpersonal influences on attentional mechanisms, especially when attending to the same spatial locations with others, could have ubiquitous real-life implications. Imagine for example, a group of students attending together to a lecture, or a couple of workers monitoring a product in an industrial assembly chain. Improving our understanding about how their attention is shaped by sharing their reality with others may for instance, give us some clues about how to optimize these environments correspondingly. In addition, in the long run, this knowledge could also allow to develop strategies aimed at better understanding and treating related clinical conditions (e.g., ADHD, Neglect syndrome). With this in mind, answering the above mentioned questions acquires tremendous relevance.

1.6.1 Dual attention paradigm

To target the central aim of this PhD thesis/work (i.e. to examine whether visual attention performance is interpersonally modulated by the task setting of an experiment partner), this Thesis proposed a modified (two-persons) version of the classic sustained visuospatial attention task (e.g., Eimer, 1996; Mangun & Hillyard, 1988; Mangun & Buck, 1998). In the typical (single person) sustained attention paradigm, a participant sits in front of a computer monitor and is asked to pay covert attention to one of two locations (e.g., left or right) throughout an experimental block (i.e., sustained attention to the left or the right side of a computer's screen) while keeping eye-gaze on a central fixation. They need to respond to visual targets randomly appearing at the attended and unattended locations as quickly as he/she can. To ensure that the participant pays more attention toward the attended location, the targets are more likely to appear at the attended location (75% of all trials; valid condition) than at the unattended location (25% of all trials; invalid condition). Reaction times (RTs) are typically faster in the valid than the invalid trials. The RT difference between valid and invalid targets indicates the attention effect, a measure of the behavioural benefit from allocating attention to the attended spatial location (Posner, 1980). The sustained attention paradigm was adapted so it could be independently performed by two people (a dyad) sat next to each other. In this “dual attention paradigm” (see *Figure 1*), the participants perform a visual go/no-go task based on a target shape (large vs. small), responding to visual targets while attending to the same spatial location or to different locations than the experiment partner. To anticipate the core finding of this thesis, in this *dual attention* setting, the data showed that a typical attention effect was present in reaction times (faster responses to targets appearing at attended locations compared to those at unattended sites) when the dyad attended to different locations, but was significantly reduced when the participants shared the attentional locus. In the following chapters of this Thesis work, this effect was investigated from cognitive, social and neuroscientific perspectives. Along this document, the name “dual attention paradigm” will be used to refer to the proposed two-persons version of the sustained visuospatial attention paradigm, and the term “dual attention effect” will refer to the reduction in the attention effect obtained when sharing the attended locations with a another person. Both the dual attention paradigm, and the dual attention effect are core elements of this thesis work and will be discussed in each of the following chapters.

Before progressing into the following chapters, it is worth reminding the different (and potentially confusing) definitions used in this Thesis regarding joint attention, social attention, shared attention and dual attention. As introduced above (see the section “Attention in dyads: joint attention and shared attention research”), this thesis will treat the definitions of joint attention (Tomasello, Carpenter, Call, Behne, & Moll, 2005 ; see also Frischen, Bayliss, & Tipper, 2007; Mundy & Newell, 2007) and social attention (Richardson & Gobel, 2015) as equivalent, and will use them to refer to gaze following/looking where others are looking. Shared attention on the other hand, is a psychological state that implies the activation of a collective perspective when experiencing the world with others (Shteynberg, 2015, 2018). While joint attention relies on behavioural observation (i.e., observing other’s looking/gazing behaviour), shared attention is a psychological state (“we-mode”) that does not require observing others. In this psychological state, the other co-attendees are not social inputs, but part of the cognitive mechanism itself (Shteynberg, 2018). Finally, as described in the previous paragraph, this thesis proposes a new concept: the “dual attention effect”. It refers to the reduction in attention performance (i.e., the reduced attention effect) obtained when sharing the attended locations with a another person in the “dual attention task” (i.e., the two-persons version of the sustained visuospatial attention paradigm here proposed).

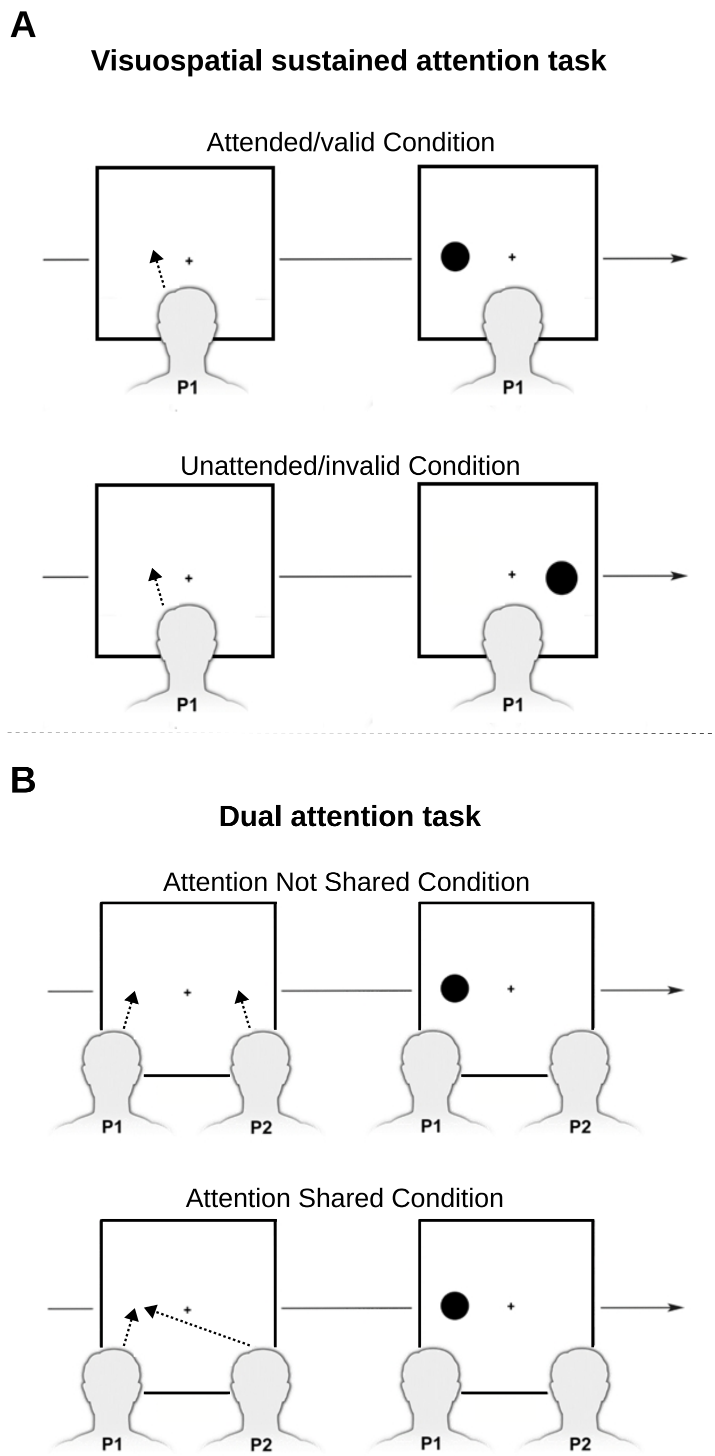

Figure 1. Classic visuospatial sustained attention task vs. the proposed dual attention task. A) Visuospatial sustained attention paradigm. A single participant sits in front of a computer monitor and is asked to pay covert attention to one of two locations (e.g., left or right) throughout an experimental block (i.e., sustain attention to the left or the right side of a computer's screen) while keeping eye-gaze on a central fixation. The participant responds to visual targets randomly appearing at the attended (valid trials; 75% target probability) and unattended locations (invalid trials; 25% target probability). Reaction times are typically faster in the valid than the invalid trials, and

the RT difference between these two conditions is known as attention effect, a measure of behavioural benefit from attention allocation to the attended spatial location (Posner, 1980). **B) Dual attention paradigm.** Participants in **a** dyad sit in front of a computer monitor and pay covert sustained attention to one of two locations in the screen (e.g., left or right) throughout an experimental block. This attended location could be shared by the dyad (attention shared condition) or not (attention not shared). Participants perform a go/no-go task (see *Figure 2* and *Figure 3* in *Chapter 2* for more details about the paradigm), responding to visual targets randomly appearing either at the attended (valid trials; 75% target probability) or unattended locations (invalid trials; 25% target probability). As discussed along this thesis, in this dyadic setting, participants showed a reduced attention effect when sharing the attended locations with the task partner, respect to the attention not shared condition. This effect was termed “dual attention effect”.

This Thesis was divided in five chapters. Chapter 2 introduced the dual attention paradigm (Exp1) and discussed the striking attention effect reduction (named “dual attention effect”) obtained when performing the task (as anticipated above). Subsequently, the social context of the paradigm (i.e., the co-actor) was removed, and attention performance was examined when a participant completed the same task alone (Exp2). The effect of perceptual load as a modulatory factor on the dual attention effect was also investigated (Exp3). Both a statistical difference between the performance in the solo and dyadic versions of the dual attention task, and the persistence of the dual attention effect under an increased perceptual load, provided support for a social account of the attention effect reduction obtained in Exp1. Chapter 3 addressed some boundary conditions by varying the social context of the task in terms of social and physical “closeness”. In particular, Chapter 3 examined the effect of group membership (i.e., social “closeness”) on the interpersonal influence on attention previously described (Exp4), and tested whether the this influence was still present when the co-actor did not shared one’s peripersonal space (i.e., physical “closeness”), but performed the task from separate room (Exp5). Chapter 4 investigated the neural underpinnings of this attention reduction effect using electroencephalography (EEG) (Exp6). ERPs were employed to study whether the effect was the outcome of sensory processing or top-down driven. These analysis were followed up using time-frequency representations and connectivity analysis to investigate the role of alpha and theta band oscillations. Taken together these findings suggested a cognitive control driven attention reduction in dyads sharing the locus of attention. Finally, Chapter 5 comprised a summary and discussion of the outcomes of the present PhD work, and described potential future lines of research and further considerations.

2

DUAL ATTENTION EFFECT:

WHEN SHARING ATTENTION DOES NOT HELP

Human evolution has shaped us into social animals, who are continually immersed in social interactions, regularly performing tasks with others and sharing our reality with them (Dunbar, 2003; Tomasello, Carpenter, Call, Behne, & Moll, 2005). For many of these interactions to be successful, it is necessary to pay attention to the same spatial locations with other individuals. We do this since childhood, while trying to learn from our parents, and continue doing it throughout our lifetime. A group of students attending together to a lecture, or a couple of workers monitoring a product in an industrial assembly chain are only a few examples where this ubiquitous “phenomena” occurs. Surprisingly however, the social and cognitive implications of this specific low-level aspect of our social life (i.e., attending to the same spatial locations with others) are not well understood. This chapter aims at contributing to the understanding of the latter (i.e., the cognitive implications) by investigating whether paying attention towards the same spatial location with another person changes/affects one’s attention performance.

Since the first year of life, we are able to follow other’s gaze and to jointly attend to the same physical objects with them (aka. joint attention; see Frischen, Bayliss, & Tipper, 2007; Mundy & Newell, 2007), a skill that facilitates sharing, coordinating and cooperating in the social world (Mundy & Newell, 2007; Tomasello, Carpenter, Call, Behne, & Moll, 2005). Gaze-triggered attention shifts have been extensively studied in the lab using a gaze-cuing paradigm (e.g., Friesen & Kingstone, 1998). Participants in this task are presented with a central picture or schematic drawing of a face that gazes to different locations (e.g., left or right). They respond to targets appearing either at the cued location or at the opposite one, with typically faster responses to the cued side. This effect is consistently present even when following the cues does not help (or even harm) task performance (e.g., Friesen & Kingstone, 1998; Friesen, Ristic, & Kingstone, 2004). The reasons underlying these effect are still being debated (e.g., Kingstone, Kachkovski, Vasilyev, Kuk, & Welsh, 2019; Wiese, Wykowska, Zwickel, & Müller, 2012;

see also Gobel, Tufft, & Richardson, 2018), but the attention shifts elicited by gaze-cues are quite reliable, and robust. Importantly for the current research, although joint attention has been intensively studied from both psychological and philosophical perspectives (Siposova & Carpenter, 2019), this investigation has been mostly focused on its relation to cooperation, bonding, theory of mind, and social learning (Mundy & Newell, 2007; Siposova & Carpenter, 2019; Tomasello et al., 2005; Tomasello et al., 2012), without consideration for the specific role of the attended spatial locations and its relation to attention performance.

Even when we are not observing others' attentional focus or following their gaze, the sole knowledge that other individuals are co-attending the same objects or tasks with us, could cause more cognitive resources to be allocated to these objects or tasks, resulting in better performance in general (Shared attention theory; Shteynberg, 2015, 2018). For instance, when presenting participants with a list of words believed to be co-attended with similar vs. different others, recall was both faster and more accurate in the former scenario (Shteynberg, 2010). Thus, shared attention may make the jointly attended objects/events more cognitively accessible and easier to recall (Shteynberg, 2010). Similarly, it has been suggested that this "shared attention state" would increase the influence of mood on evaluative judgements making them more extreme (Shteynberg, Hirsh, Galinsky, & Knight, 2014), induce more intense emotional reactions to the co-attended objects (Shteynberg, Hirsh, Apfelbaum, et al., 2014), boost individual goal pursuit for co-attended goals (Shteynberg & Galinsky, 2011), and intensify imitation, favouring social learning (Shteynberg & Apfelbaum, 2013). According to Stheynberg's theory, shared attention activates a psychological state ("we mode") in which one's perspective becomes collective (i.e., is also the other person's perspective) (Shteynberg, 2015, 2018). This state however, and it's cognitive implications (i.e., more elaborate processing of the co-attended objects/tasks), would only occur if people believe they are simultaneously co-attending (to the objects or tasks) with similar others (i.e. members of the same group) (Shteynberg, 2014, 2015). As in joint attention-related research, the specific role of the attended spatial locations and its relation to attention performance has not been considered by the shared attention field.

A few studies have reported interpersonally driven modulations in performance when completing attention-related tasks in dyads (Böckler, Knoblich, & Sebanz, 2012; Gobel, Kim, & Richardson, 2015; Gobel et al., 2018; He, Lever, & Humphreys, 2011;

He et al., 2014; Welsh et al., 2005, 2007). He, Lever, and Humphreys (2011), for instance, found that the knowledge about the contents in a co-actor's working memory can guide the spatial allocation of visual attention in a visual search task (aka. interpersonal memory guidance of attention), suggesting that memory information could be used to guide attention interpersonally. This, however, is specific for situations of attention deployment while maintaining memory contents, therefore may not be able to reveal an interpersonal influence utterly related to attentional mechanisms. A more specific view into attentional modulations in dyadic tasks was proposed by Böckler, Knoblich and Sebanz (2012). In their study, Böckler, Knoblich and Sebanz (2012) modified the Navon task (Navon, 1977), so it could be performed by co-acting individuals. In the original (solo version) of the task, a large letter (global stimulus feature) formed by many small letters (local stimulus feature) is displayed. Participants needed to discriminate/identify either the local or the global feature of the stimuli. Faster responses are usually performed to the global compared with the local stimulus features. Moreover, regardless of the focus of attention (local or global), responses are typically impaired/slowed down when these features are incongruent (e.g., attending to the global feature when the stimuli is a large letter H formed by small letters Ss), compared to the congruent condition (e.g., attending to the global feature when the stimuli is a large letter H formed by small letters Hs). When performing the two-persons version of the task (Böckler, Knoblich, & Sebanz, 2012), a dyad were either focusing on the same (e.g., both people attending to the local stimulus features) or different (e.g., one person attending to the local feature, and the other person focusing on the global feature of the stimulus) aspects of the task. Responses under this setting were slower when the co-actor had a different focus of attention, suggesting that the different attentional focus employed by (or instructed to) the co-actor interfered with one's own focus when performing the task (Böckler, Knoblich, & Sebanz (2012); but see Brennan, Chen, Dickinson, Neider, & Zelinsky (2008), and Wahn, Kingstone, & König, 2017, for evidence suggesting that the availability of information about a co-actor's task/actions and/or performance can be greatly advantageous in dyadic visuo-spatial tasks where collaboration is requested).

Further evidence suggested that even very basic and robust attention orienting mechanism may be modulated by social contexts. inhibition of return (IOR) is a slowing of responses to targets presented at previously attended locations resulting from an inhibitory mechanism keeping attention away from previously attended events/locations (Klein, 2000). It has been shown that this robust attention orienting effect is also present when responding to locations previously attended by another person (Gobel et al., 2018; Tufft, Gobel, & Richardson, 2015; Welsh et al., 2005, 2007). Although initial evidence for this came from arm-reaching tasks in dyads (Welsh et al., 2005, 2007), I will focus here on more recent evidence employing a classical spatial orienting paradigm where the social relevance of the cues was manipulated (Gobel et al., 2018).

Gobel, Tufft, and Richardson (2018) used the classical cued version of the IOR task (see Klein, 2000), and manipulated the participant's beliefs regarding the origin of the cues. Participants sat back-to-back with another individual (Exp1), and were told that the cues in the task were either randomly generated by a computer (non-social condition), or that they indicated the gaze behaviour of a second person (social condition). Although the cues were always randomly generated, when the participants believed that the cues reflected the gaze position of the other person, they showed larger IORs compared to the non-social condition. A second experiment extended this finding by showing that the effect is modulated by the social hierarchy attributed to the co-actor. The effect was stronger when the cue was believed to indicate the gaze of a higher social rank/status individual. This however, only occurred when the experiment partner was believed to be engaged in the same task, echoing previous findings related to the shared attention theory by Shteynberg (2015).

Taken together, Gobel et al.'s experiments showed that not only the physical saliency of the cues, but also their social relevance matters in spatial orienting. This also was the first reported evidence showing that basic attentional processes can be interpersonally modulated by social context (see also Tufft, Gobel, & Richardson, 2015). However, this investigation was performed exclusively on the inhibition of return (IOR). Considering that different attentional processes are thought to be relatively independent or not interrelated in terms of the underlying mechanisms (e.g., Pan, Wu, & Zhang, 2017; Slessor et al., 2019), further research is needed to examine the extent to which social context and interpersonal influences modulate other basic attentional processes apart from the IOR.

As introduced above, the present chapter aims at extending the current understanding regarding interpersonal influences in basic human attention by investigating to whether attention towards the same spatial location with another person changes/affects attention performance. In particular, this Chapter asked whether human visual attention acts differently (i.e., attention performance is changed) when another person pays attention to the same location with us, in the absence of direct communication or explicit interactions (i.e.., without gaze following/coordination or a speech exchange), just by knowing that the locus of attention is shared, even if this knowledge is irrelevant/trivial for one's task/goals/performance. Answering this question goes beyond the two main lines of research reported in literature to date: joint attention (e.g., Mundy & Newell, 2007) and shared attention (e.g., Shteynberg, 2015). By excluding gaze following, this question extends traditional research in the joint attention field (e.g., Frischen et al., 2007; Mundy & Newell, 2007)**,** which has aimed at studying attention coordination based on behavioural observation of other person's attentional focus. By focusing on the attended spatial locations, this research complements research in the shared attention field (e.g., Shteynberg, 2014, 2015, 2018), which examines the cognitive, affective and behavioural consequences of knowing that we share attention towards the same objects/ tasks with other individuals, without considering the specific role the attended locations may play.

In order to address this question, a modified (two-persons) version of the classic sustained visuospatial attention paradigm (e.g., Eimer, 1996; Mangun & Hillyard, 1988; Mangun & Buck, 1998) was employed. In a typical (single person) sustained attention paradigm, a participant sits in front of a computer monitor and is asked to pay covert attention to one of two locations (e.g., left or right) throughout an experimental block (i.e., sustain attention to the left or the right side of a computer's screen) while keeping eye-gaze on a central fixation. They need to respond to visual targets randomly appearing at the attended and unattended locations as quickly as he/ she can. To ensure that the participant pays more attention toward the attended location, the targets are more likely to appear at the attended location (75% of all trials; valid condition) than at the unattended location (25% of all trials; invalid condition). Reaction times (RTs) are typically faster in the valid than the invalid trials. The RT difference between valid and invalid targets indicates the attention effect, a measure of behaviour benefit from attention allocated to the attended spatial location (Posner, 1980). The sustained attention paradigm was adapted so it could be independently performed by two people (a dyad) sat next to each other. In this "dual attention paradigm" (see *Figure 2*), participants perform a visual go/no-go task, responding to visual targets while attending to the same spatial location as or to a different location that an experiment partner attends to.

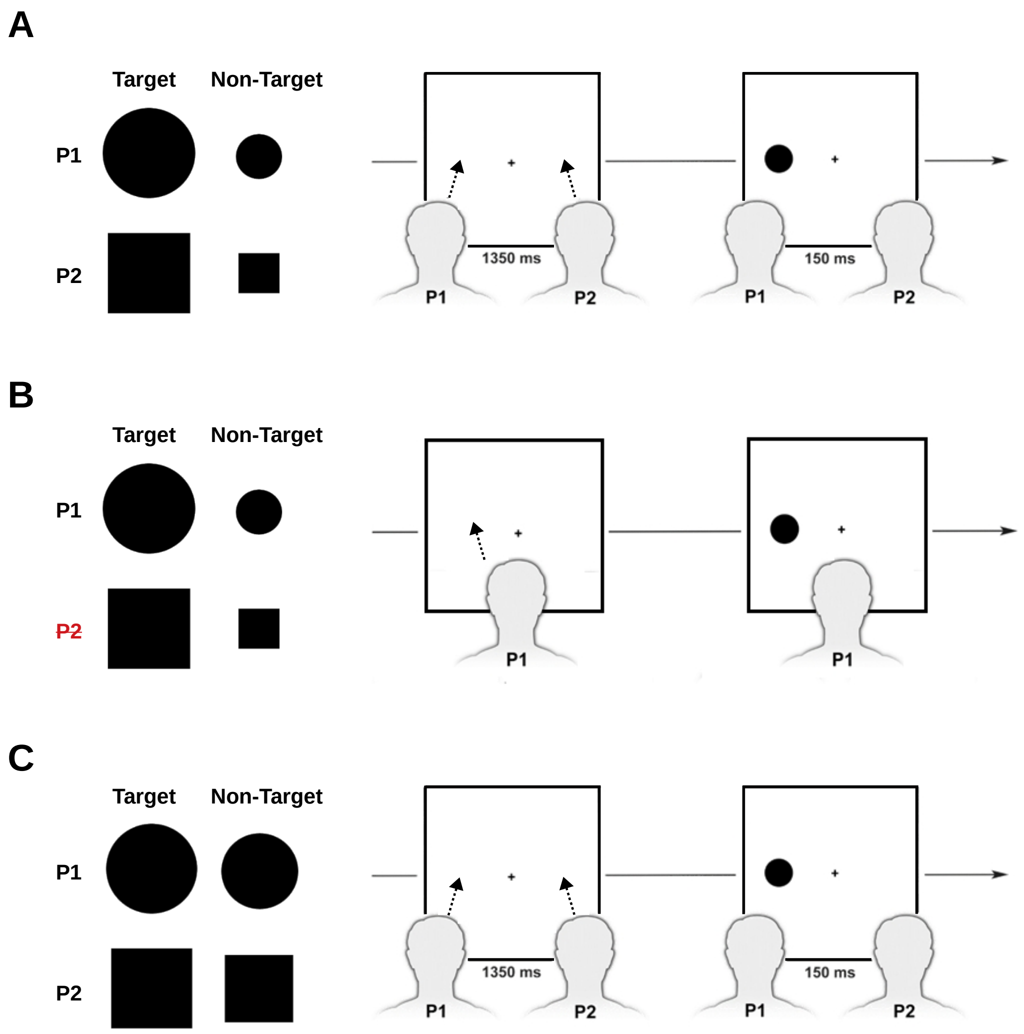

Figure 2. The Dual attention task. Participants sit in front of a computer monitor and pay covert sustained attention to one of two locations in the screen (e.g., left or right) throughout an experimental block while keeping eye-gaze on a central fixation. This attended location could be shared by the dyad (attention shared condition) or not (attention not shared). Participants respond to visual targets (i.e., circles or squares, large or small) randomly appearing either at the attended (valid trials; 75% target probability) or unattended locations (invalid trials; 25% target probability)(see *Figure 3*. for more details about the distribution of stimuli in the task). They perform a go/no-go task, responding to the large target shapes while ignoring the small ones. **A) Experiment 1.** Dual attention task with an easy size discrimination. In this example, participants sustained covert attention to different visual fields, as indicated by the arrows. In this case, Participant 1 (P1) responded to circles, and Participant 2 (P2) responded to squares. They both performed a go/no-go task, responding to the large shapes while ignoring the small ones. Non-target stimuli were about 30% of the size of the targets. **B) Experiment 2.** Solo version of the dual attention task. The paradigm was the same as in Experiment 1. The only change was that a single participant (instead of a dyad) performs the task. The stimuli for the “second” participant (non-existent in this case) were kept like in Experiment 1, but they should be ignored. In this

example, the participant payed sustained covert attention to the left side of the screen, as indicated by the arrow. **C) Experiment 3.** Dual attention task (two-person version) with an increased task load. The higher load was achieved by increasing the similarity between the sizes of target and non-target stimuli, making the discrimination task more difficult to perform. Size-wise, the non-target stimuli in Experiment 3 were about 75% of the target ones. The size of the target stimuli remained the same as in E1.

As discussed above, the shared attention theory posits that when co-attending towards the same objects or tasks with other individuals, enhanced general performance is achieved. The relevance of the attended spatial locations however, has not been examined by this theory. In the current paradigm, participants performed a go/no-go task while sharing or not the attended spatial locations on a computer screen. If the shared attention theory proposal/findings translate directly into the paradigm here proposed (i.e., the dual attention paradigm), an enhanced performance in the dual attention task when the attended locations are shared by the dyad would be expected. This enhanced performance would be reflected by a larger attention effect (i.e., a greater RTs difference between valid and invalid trials), for the attention shared condition, relative to the condition in which the attentional locus was not shared by the two individuals.

It has also been suggested that, while performing together with another person, one might represent the co-actor's task parameters/features as one's own, even if irrelevant for one's performance (co-representation account; Knoblich & Sebanz, 2006; Sebanz & Knoblich, 2009; Sebanz, Knoblich, & Prinz, 2003). An extreme scenario applicable to the dual attention task would be that, due to co-representation, each individual in the dyad mentally represents the whole task set, including both one's and the partner's task parameters (e.g., attended locations and target stimuli). If this is the case, due to the co-representation of the target shapes, the task would turn into a typical sustained attention paradigm with 75% probability of valid trials (i.e., targets appearing at the attended side, considering both one's and the partner's targets) for the attention shared condition, and 50% probability for attention not shared case. The result would be a typical attention effect (i.e., faster RTs for valid trials) for the attention shared condition, and a null effect for the attention not-shared scenario. According to this reasoning, also in this case (see the shared attention theory related reasoning above), a stronger attention effect would be expected for the attention shared scenario.

Co-representing the attended locations echoes the case of the joint Navon task (Böckler et al., 2012), even though the specific role of the attended spatial locations was not considered therein. As presented above, in the joint Navon task, participants respond to the identity of letters in a two-choice Navon task, while focusing either on the same or different aspects of the task (local or global features). In this case, responding when the co-actor had a different focus of attention interfered negatively on task performance (Böckler et al., 2012), potentially due to a conflict induced by mental representations of the co-actor's divergent focus in the task (Böckler & Sebanz, 2012). This finding, if translated into the dual attention task/context, could be taken to suggest a reduced performance when individuals in the dyad pay covert attention towards different spatial locations in the screen. Therefore, considering either the full co-representation account or the evidence from the distinct attentional focus in the joint Navon, a larger attention effect would be expected when the dyad shares the attended spatial locations in the dual attention task (or, in other words, reduced for the not shared condition).

In the current Chapter, three experiments are presented. Experiment 1 introduces the dual attention paradigm and discusses the variation in attention performance when sharing or not the attended locations with another person. Anticipating the outcome, a striking reduction in attention performance (i.e., a reduced attention effect) was obtained when the dyad shared the attended spatial locations in the dual attention task. In Experiment 2, the social context of the paradigm (i.e., the task partner) was removed, and the outcome of a participant completing the same task alone was investigated. Finally, Experiment 3 investigated the dual attention effect when increasing the difficulty (perceptual load) of the original task.

2.1. Experiment 1

Experiment 1 examined whether visual attention performance is interpersonally modulated when an experiment partner is either sharing or not one's attended spatial locations in a dyadic sustained attention a task (aka., dual attention paradigm; see *Figure 2*, and the introductory section above).

2.1.1 Method

2.1.1.1 Participants

Forty-eight volunteers (24 dyads) participated in Experiment 1 (39 females; 40 right handed; M_{age}= 20.79, SD_{age}= 2.85). They reported normal or corrected-to-normal vision. All participants provided written informed consent to take part in the study, and were given either one (1) course credit or eight pounds (£8) for their participation. Participants in the same dyad reported not having a close relationship. All the experiments in this Thesis received ethical approval from the Bournemouth University Ethics Committee.

2.1.1.2 Design

The current experiment employed a 2x2 factorial design, where Attention (attended vs. unattended location) and Sharing (attention shared vs. notshared) were manipulated within-subjects. The dependent variables were the participant's reaction times (*RTs*) and accuracies (percentage of correct responses) to the target stimulus. Of particular interest was the interaction between these two factors (Attention x Sharing), representing the interpersonal influence in the task (i.e., the changes in attention performance when sharing or not the attended spatial locations with the task partner).

2.1.1.3 Materials and procedure

E-prime 2.0 was used to program the experiment, control the experimental flow and record the responses. Participants in a dyad sat side by side next to each other in front of a computer monitor (viewing distance: 70 cm to screen centre) and independently completed a sustained visual attention task. During each trial, participants were instructed to fixate on a white cross displayed at the centre of the computer's screen, while focusing their attention to one side of the visual field (i.e., left or right) for an entire experimental block. The task partner's visual attention was either focused on the same side (attention shared) or different sides (attention not shared) of the visual field. Circles or squares, large or small, were randomly displayed at the left or right side of the screen, one per trial. Participants performed a go/no-go task. Each person in the dyad was assigned a stimulus shape (e.g. Participant 1 responding to squares, Participant 2 responding to circles; counterbalanced across participants) and had to quickly respond exclusively to the large version of the stimuli with their assigned shape (e.g. Participant 1 responds only to large squares, Participant 2 to large circles), regardless of the side of the screen it was displayed at. Responses had to be withheld to non-targets (i.e. the small stimuli) and the shape not assigned to the participant. The size of the large stimuli was set to 4.57° x 4.57°. The size of the small stimuli was 2.38° x 2.38°. Stimuli were presented in white against a black background. 75% of the target stimuli appeared on the attended side of the screen (valid trials), while 25% of them appeared at the opposite location (invalid trials). The overall stimulus distribution was balanced, so that an equal number of stimuli were displayed for the shared and not shared conditions (see *Figure 3*). Responses were made with a left-mouse-click for the participant sat on the right, and with a “space bar” key press for the person sat on the left. Each experimental session had eight blocks, varying the instructed focus of attention to the left or right side of the visual field (e.g., along a specific block, the attended side for each participant could be as follows: P1:left / P2:left, or P1:left / P2:right, or P1:right / P2:left, or P1:right / P2:right; P1=Participant 1, P2=Participant 2). Therefore, visual attention across blocks was either focused on the same side (attention shared) or different sides (attention not shared) of the visual field. These task instructions changed every two blocks. The stimuli were displayed for 150ms, with an inter-trial-interval (ITI) of 1350ms. The experiment included a total of 1280 trials. From these, 640 were go-trials that required responses from the participants (i.e., 320 for each subject in a dyad). Short breaks were allowed each 160 trials. Each participant was informed about the experiment partner’s instructions at the beginning of each experimental block. They had to acknowledge reading the instructions regarding the experiment partner’s task. However, they were told explicitly not to monitor the partner’s task.

Participants also responded to several questionnaires. Before the computer-based trials, they completed the *Individualism-Collectivism* scale (*IND-COL*; Singelis, Triandis, Bhawuk, & Gelfand, 1995) to measure the degree to which participants saw their selves as members of a collective/social group (i.e., collectivism) or as independent selves (i.e., individualism). The *IND-COL* scale can be divided into four subscales measuring horizontal collectivism (*HC*), vertical collectivism (*VC*), horizontal individualism (*HI*), and vertical individualism (*VI*). The *horizontal dimension* reflects the degree to which individuals in a group are considered similar to each other, while the *vertical dimension* shows whether hierarchies/inequalities are accepted. In this line, *HC* people merge themselves into groups where all the parts are considered as equal. *VC* individuals accept hierarchies, while still acting as a collective, and are willing to sacrifice themselves in pro of the group benefit. *HI* people are more independent, while considered as equals in relation to the rest of the group. Finally, *VI* individuals are very independent and competitive, and accept marked hierarchies/inequalities between people (He, Sebanz, Sui, & Humphreys, 2014; Singelis et al., 1995). Given that the *VC* and *HC* scores have been shown to be highly correlated (Triandis & Gelfand, 1998; Triandis, 1995), they are typically merged into a Combined Collectivism score (e.g., He et al., 2014). Here I followed this suggestion and summed their scores to create a single Collectivism measure.

After completing the computer-based section of the experiment, participants filled in the *Autism-spectrum Quotient* (AQ; Baron-Cohen et al., 2001). For each of the 50 items in this questionnaire, participants had to choose one out of four scale-points from “definitely disagree” to “definitely agree”. These items measure autistic-like traits across the general population (Baron-Cohen et al., 2001). Subsequently, participants completed the 40 items of the *State-Trait Anxiety Inventory* (STAI; Spielberger, 2012), employed to assess trait and state anxiety. In this inventory, 20 items assessed how anxious the participants felt at the moment of answering the questionnaire (state anxiety; Form Y1), while 20 items examined how participants generally felt and their anxiety-proneness (trait anxiety; Form Y2).

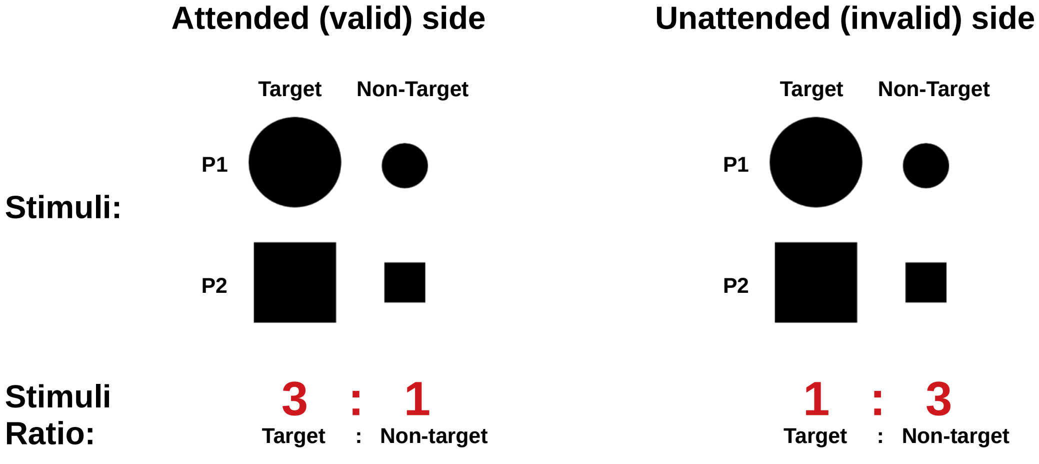

Figure 3. Stimuli distributions in the dual attention task. 75% of the target stimuli appeared at the attended side of the screen (valid trials), while 25% of them appeared at the opposite location (invalid trials)(i.e., 3:1 ratio, valid targets:invalid targets). To compensate for the intrinsic imbalance in the target distributions, the distribution of non-target stimuli was also modified. 75% of the non-target shapes appeared at the unattended side, while 25% were displayed at the attended location(i.e., 1:3 ratio, valid

non-targets:invalid non-targets). In this way, the probability of having a stimulus appearing at either side of the screen was matched across experimental block. This also means that the overall stimulus distribution was balanced, so that an equal number of stimuli were displayed for the shared and not shared conditions.

2.1.1.4 Statistical Analyses

All analyses were performed using R (version '1.1.456') and RStudio (RStudio Team, 2016). Eight participants were excluded from statistical analysis due to accuracies below 75% in any design cell. The remaining 40 participants (32 females; 32 right handed; M_{age}= 21.12, SD_{age}= 3.01) were considered for further analysis.

Measures of central tendency - Accuracies and Reaction times (RTs) data were analysed using both classic ANOVAs on means, and robust methods on 20% trimmed means. Robust methods are designed to work well both in the presence and absence of violations in the statistical assumptions, and can help increasing statistical power (Erceg-Hurn, Wilcox, & Keselman, 2013; Field & Wilcox, 2017; Wilcox, 2012; Wilcox & Rousselet, 2018). As part of this literature, it has been shown that tests on trimmed means tend to provide a better and more robust description of the central tendency of a distribution than their arithmetic counterpart (i.e., arithmetic mean) (Erceg-Hurn et al., 2013; Field & Wilcox, 2017; Wilcox, 2012; Wilcox & Keselman, 2003; Wilcox & Rousselet, 2018). In this thesis, on the relevant statistical contrasts, I employed the percentile bootstrap method on 20% trimmed means (see Rousselet, Pernet, & Wilcox, 2019b, 2019a, for some recent tutorials) to follow up the classic ANOVA results. In this way, I assessed their robustness to outliers and to violations in statistical assumption. For the robust method (i.e., the percentile bootstrap on 20% trimmed means), the results are presented including the difference between trimmed means $\hat{\psi}$ (*psihat*) for the relevant contrasts, as well as the associated bootstrap confidence interval and the respective *p*-value (at α =0.05). The R packages '*ez*' (Lawrence, 2016) and *'WRS'* (Wilcox & Schönbrodt, 2014) were employed to compute classic ANOVAs and Robust Statistics respectively. From the '*WRS*' package, the functions '*bwwmcppb', 'wwwmcppb', 'bwmcppb',* and *'wwmcppb'*, were employed. These functions implement the percentile bootstrap method on trimmed means according to the experimental design (i.e., *'bwwmcppb'* for a between-by-within-by-within design; *'wwwmcppb'* for a within-by-within-by-within design; '*bwmcppb'* for a between-by-within design; '*wwmcppb'* for a within-by-within design). These functions and methods are described in detail in (Wilcox, 2012).

Bayes Factors (BF) – For the relevant statistical interactions, Bayes Factors were computed using the '*BayesFactor*' R package (Morey & Rouder, 2015), with the default prior (Jeffreys-Zellner-Siow, JZS; Jeffreys-beta for correlation analysis) . This choice (i.e., the use of the default prior) has been suggested when no prior information about the effects of interest is available (e.g., Rouder et al., 2012, 2009; Wagenmakers et al., 2018), like was here the case. Bayes Factors were reported expressing the probability of the data given the alternative hypothesis, relative to the null (BF10), or the probability of the null relative to the alternative hypothesis (BF01). Following Wagenmakers et al. (2018), BFs from 1-3 were considered as representing "anecdotal" evidence, BFs from 3-10 as "moderate" evidence, and so on.

Correlation Analysis **–** The scores from the *Individualism-Collectivism (IND-COL)* subscales, the *Autism-spectrum Quotient* (*AQ)*, and the *State-Trait Anxiety Inventory (STAI)*, were correlated to the dual attention effect obtained in the dyadic sustained attention task. The dual attention effect was calculated by subtracting the typical attention effect ($M_{AttEffect} = M_{RTs,unattended} – M_{RTs,attended}$) for the attention shared condition from attention effect for the unshared condition (i.e., $M_{dualAttEffect} = M_{\text{AttEffect, unshared}} – M_{\text{AttEffect, shared}}$). I employed Spearman's correlations in all cases. These are reported alongside Bayes Factors, obtained after running Bayesian correlations with the Jeffreys-beta prior (Ly, Verhagen, & Wagenmakers, 2016).

2.1.2 Results

2.1.2.1 Accuracies

Participants' overall performance was high ($M_{\text{ACC, Exp1}}$ = 97.1 %, 95% CI [95.74, 98.54]). Mean accuracies (see *Table 1*), were submitted to a 2x2 repeated-measures ANOVA with Attention (attended vs. unattended) and Sharing (shared vs. unshared) as within-subjects factors. No statistically significant effect was obtained, nor when employing the within-within robust ANOVA on 20% trimmed means with the percentile bootstrap method.

Table 1. Mean accuracies (with SD) for Experiment 1. Mean accuracies are here presented as percentage of correct responses.

Experimental Condition			
Notshared		**Shared**	
Attended	**Unattended**	**Attended**	**Unattended**
97.5(4.15)	96.3(5.63)	97.3(5.05)	97.5(4.30)

2.1.2.2 RTs

Go-trials were analysed. From these, only trials with correct responses were considered (97.1%). Following Leys et al.´s (2013) suggestion, outliers were determined and removed using a threshold of 2.5 times the Median Absolute Deviation (MAD) per design cell. This eliminated 4.5% of the remaining data.

Mean RTs data (see *Figure 4,* and *Table 2*) were submitted to a 2x2 repeated-measures-ANOVA with Attention (attended vs. unattended) and Sharing (shared vs. unshared) as within-subjects factors. The ANOVA revealed a significant main effect of Attention, $F(1, 39) = 70.45$, $p < .001$, η_G^2 =0.068, due to shorter RTs for the attended stimuli (M = 411 *ms*, 95% CI [396.08, 426.43]) than for the unattended ones (M = 438 *ms*, 95% CI [422.38, 453.82]). The main effect of Sharing was not significant, $F(1, 39) = 0.99$, $p = .325$. More importantly, the attention effect varied across sharing conditions, as indicated by the significant interaction Attention x Sharing, $F(1, 39) = 9.10$, $p = .004$, η_G^2 =0.004. The attention effect was smaller when attention was shared by the dyad (M = 21 *ms*, 95% CI [13.68, 27.58]), $F(1, 39) = 36.06$, $p < .001$, η_G^2 = 0.04, than when it was not shared (M = 33 *ms*, 95% CI [24.68, 41.43]), $F(1, 39)$ =63.76 , $p < .001$, η_G^2 = 0.10.

These results were in line with those obtained when computing within-within design percentile bootstrap on 20% trimmed means. The main effect of attention was significant, $\hat{\psi}$ = -53 [-66, -40.8], $p = 0$, the main effect of Sharing was not significant, $\hat{\psi}$ = -8 [-21.7, 5.01], p =.223, and there was a significant interaction Attention x Sharing, $\hat{\psi}$ = -12 [-20.9, -3.06], p =.006.

For the Bayes Factors Analysis, the attention effect was calculated (i.e., subtracting the RTs for the attended condition from the RTs for the unattended condition). The attention effect was compared across Sharing conditions, yielding a BF10 = 2.267, representing “anecdotal” support for the model with the Sharing effect, relative to the null model, provided the data. In other words, BFs remained insensitive (Wagenmakers et al., 2018).

Post-hoc simple main effects analysis examined the effect of Sharing separately for the each of the Attention conditions. Both the ANOVA and the percentile bootstrap method on 20% trimmed means yielded a significant difference between the participants RTs to attended locations across Sharing conditions, $F(1, 39) = 6.33$, $p = .016$, $\eta^2_G = 0.01$; $\hat{\psi} = -8.86$ [-15.6, -2.79], $p = .004$, due to slower RTs when dyads shared the locus of attention, than when this locus was notshared (see *Table 2*). Response times to unattended locations were not statistically different across Sharing conditions, $F(1, 39) = 0.20$, $p = .653$; $\hat{\psi} = 1.18$ [-7.89, 10.2], $p = .726$.

2.1.2.3 Correlation Analysis

The correlation between the AQ and the dual attention effect was statistically significant, $r_s = 0.340$, $p = .034$, BF10 = 3.7. No other correlation was significant (see *Table 3)*.

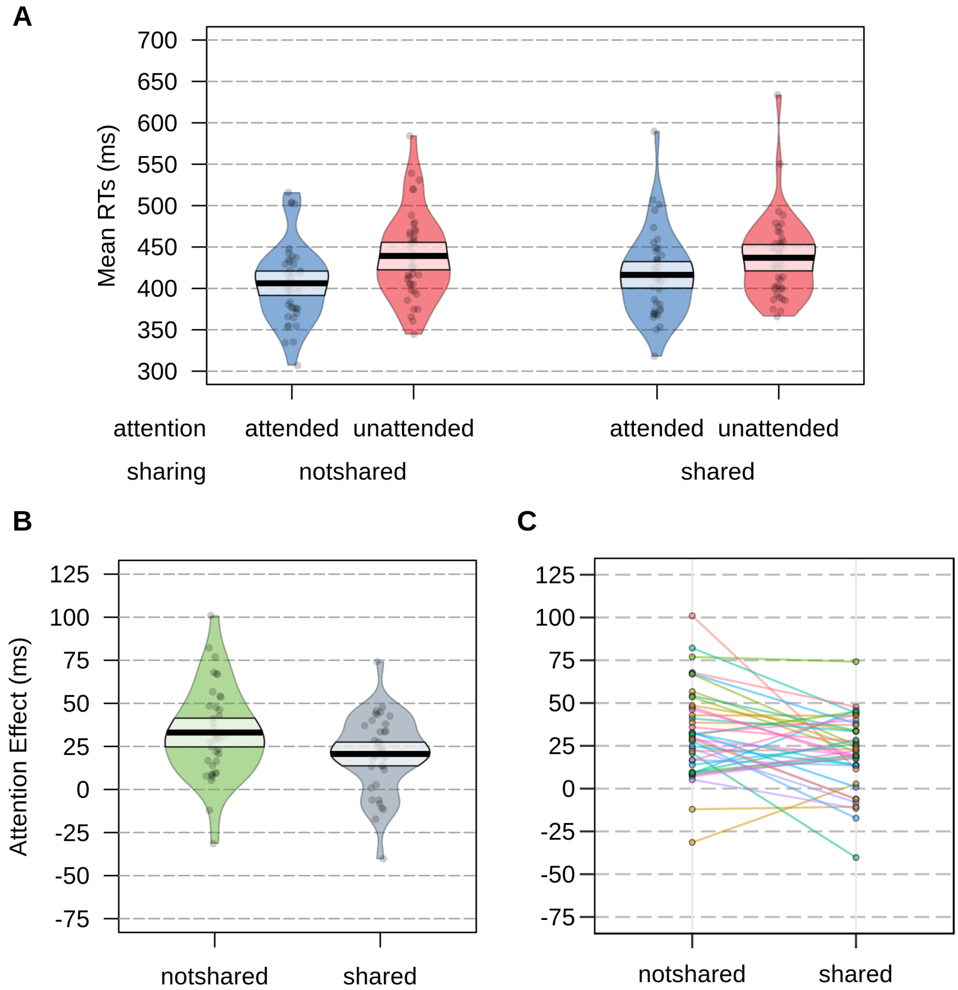

Figure 4. Results Experiment 1. A) Mean RTs as a function of attention (attended, unattended), and sharing (shared, not shared) conditions. The group mean for each condition is displayed with 95% confidence intervals (CIs). **B)** Mean attention effect across sharing (shared, not shared) conditions. The attention effect is calculated as the difference between the mean RTs for the unattended condition and the mean RTs for the attended condition (i.e., $M_{AttEffect} = M_{unattended} - M_{attended}$). Means are displayed with 95% CIs. A reduction in the attention effect was obtained when the dyad shared the attended spatial locations (shared condition). This was termed *dual attention effect*. **C)** Stripchart showing the attention effect for each participant across sharing conditions. Lines were drawn to join paired observations. Out of the 40 participants analysed, 27 (~ 67.5% of the group) showed an effect in the same direction than the group mean (i.e. a reduction of the attention effect for the attention shared condition).

Table 2. Mean RTs in ms (with SD) for Experiment 1.

Experimental Condition			
Notshared		**Shared**	
Attended	**Unattended**	**Attended**	**Unattended**
406(47)	439(52)	416(51)	437(51)

Table 3. Correlations in Experiment 1. The scores from the *Individualism-Collectivism (IND-COL)* subscales, the *Autism-spectrum Quotient* (*AQ)*, and the *State-Trait Anxiety Inventory (STAI)*, were correlated to the dual attention effect ($M_{dualAttEffect} = M_{\text{AttEffect, unshared}} - M_{\text{AttEffect, shared}}$). Spearman's correlations and Bayes Factors are reported in all cases.

Individualism-Collectivism (IND-COL) *(N*=40*)*	-
Combined Collectivism (HC+VC)	r_s = 0.152, *p* = .349, BF10 = 0.529
Horizontal Individualism (HI)	r_s = 0.130, *p* = .423, BF10 = 0.652
Vertical Individualism (VI)	r_s = 0.116, *p* = .477, BF10 = 0.356
State-Trait Anxiety Inventory (STAI) *(N*=39*)*	r_s = -0.039, *p* = .814, BF10 = 0.420
State Anxiety (Y1)	r_s = -0.127, *p* = .440, BF10 = 0.360
Trait Anxiety (Y2)	r_s = 0.061, *p* = .706, BF10 = 0.505
Autism-spectrum Quotient (AQ) *(N*=39*)*	r_s = 0.340, *p* = .034, BF10 = 3.700

2.1.3 Discussion

Strikingly, when performing the *dual attention* task, participants in Experiment 1 showed a reduced attention performance (i.e., a smaller attention effect) when sharing the attended spatial locations with the task partner, than when their locus of attention differed. This reduction in attention performance when sharing the locus of attention was termed *dual attention effect*. The current finding (i.e., the dual attention effect) adds to the emerging body of evidence suggesting that social context and interpersonal influences from other individuals in our environment influence even basic human cognitive processes (e.g., Gobel et al., 2018; Tufft et al., 2015), in this case, visual attention performance.

However, the direction of the effect here obtained is the opposite to what was anticipated given related findings reported in literature (e.g., Knoblich & Sebanz, 2006; Shteynberg, 2015). For instance, a co-representation account of these results may be more complicated than previously thought. It has been suggested that, when performing together with another individual, people mentally represent the partner's actions/tasks as their own (aka. task co-representation; Sebanz et al., 2003). Here, an extreme case of co-representation would imply individuals co-representing the full task set assigned to the dyad, including attended locations and target stimuli. Co-representation of the stimuli (i.e., similarly representing one's stimuli and those assigned to the task partner) would turn the task into a classic visuospatial sustained attention paradigm. In this case, given the unbalanced distribution of targets (see *Figure 3*), 75% of the target shapes (considering both one's and the partner's) would appear at the attended side when the dyad attended to the same spatial locations (attention shared condition), while 50% of the targets would be displayed at the attended side in the situation in which the dyad did not share the locus of attention (attention not shared condition). These probabilities would elicit a typical attention effect (i.e., faster RTs for valid trials) for the attention shared condition, and a null attention effect for the attention not-shared scenario[1]. This was clearly not the result here obtained. Instead, the pattern here presented pointed towards the opposite direction: a smaller attention effect for the shared condition. Similarly, co-representing the (same vs. different) attended locations in the current task would seem analogue to co-representing the (same vs. different) focus of attention in a joint Navon task (Böckler et al., 2012). In the case of the joint Navon, responding when the co-actor had a different focus of attention reduced performance in the task (Böckler et al., 2012), potentially due to a conflict induced by mental representations of the co-actor's divergent focus (Böckler & Sebanz, 2012). Contrary to this, in the dual attention task, the reduced performance was found when participants in the dyad shared the attended spatial locations. Therefore, the evidence here reported suggests that focusing on the same vs. different aspects, and focusing on the same vs. different spatial locations, may affect performance in different ways. In addition, the current result cannot be accounted for by participants fully co-representing the stimuli/task set assigned to the dyad along the task.

Although an extreme case of co-representation seems unlikely to explain the current findings, a co-representation-driven response inhibition could be related to the dual attention effect. It may be the case that due to co-representation of the (task) partner's stimuli, the partner's targets could prime one's own target-relevant response, with a subsequent need to inhibit this primed response given one's instructions set (i.e.,

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1 The thesis does not include an experiment with a single isolated participant performing both parts of the task (i.e., a single participant responding to both large circles and large squares) since this would be equivalent to a classic sustained attention paradigm with two different valid trials probabilities (i.e., 75% vs. 50% probability of valid trials).

to withhold responses for one's non-targets). Following the above-mentioned unbalanced distribution of target stimuli in the task (see *Figure 3*), the attention-shared condition was characterised by a higher probability of target stimuli (considering both one's and the partner's) appearing at the attended location, compared to the attention-notshared scenario. This unbalanced distribution would provoke a stronger need to inhibit primed responses (by the partner's targets) in the attended-shared condition, potentially eliciting the attention performance reduction measured by the dual attention effect.

Wolf, Launay and Dunbar (2016) showed that jointly attending towards the same spatial location with another person increases the reported/perceived levels of affiliation/bonding/closeness in relation to the co-attending person. Wolf et al. (2016) argued that this enhanced perception of closeness could be due to a minimal-group like categorisation elicited by joint attention. In this line, a person sharing the attended location would be categorised as an in-group member, while a person attending to a different location would be perceived as an out-group. Task co-representation in joint action settings has been found to be enhanced (or present exclusively) when performing with in-group members (Aquino et al., 2015; Hommel, Colzato, & van den Wildenberg, 2009; McClung, Jentzsch, & Reicher, 2013; but see He et al., 2011). Therefore, in relation to the (potential) intergroup categorisation induced by sharing (or not) the locus of attention, and considering the role of group membership in co-representation, it could happen that when completing the dual attention task, people take into account the co-actor's task more seriously (or make stronger representations of it) when the attentional locus is shared. This could depict an increased interference with one's performance (e.g., more attention directed to the others shape), resulting in the attention reduction when the dyad shared the attended spatial locations. Accordingly, although (as described above) co-representing the full task set corresponding to the dyad cannot account for the effect here obtained, it could happen that some aspects of the partner's task (e.g., the partner's stimuli or her target shapes) matter to some extent, and may interfere with one's performance with a different strength depending on the dyad's attentional locus (with a stronger interference for the shared condition). Importantly however, this could be a circular argument. It may well be that taking into account more closely the other person and his/her task could have led to an increased bonding reported by Wolf et al. (2016). Yet, this last argument has not been tested, thus it is just speculation at the current stage.

Indeed, among the candidate explanations behind the above-mentioned augmented bonding/affiliation/closeness (when sharing the attentional locus), Wolf and colleagues also argued that the knowledge of being sharing the attended spatial location with another person may elicit extra higher order processing like mentalising, opening the possibility of attributing social behaviours to the co-attending person, enhancing the perceived closeness. Indeed, it would not be surprising that merely knowing that the other person shares one's locus of attention could be analogue to obtaining this information (about the other's attentional locus) through gaze following, subsequently activating the series of higher order processes supporting joint attention and facilitating coordination in the social world (e.g., monitoring others, mentalising; see Mundy & Newell, 2007; Tomasello, Carpenter, Call, Behne, & Moll, 2005). If sharing the attentional locus with another individual induces extra higher order processes (e.g., mentalising about or monitoring the other individual), this extra processing may consume additional attentional resources respect to the condition in which the dyad did not share the attended locations. The additional resources deployed to a "secondary" task (like mentalising/monitoring) in the former scenario (attention shared) could explain the associated attention performance drop.

In a similar vein, recent evidence has suggested that the presence of others, depending on the context (see below), could exhaust an important part of executive attention (Belletier, Normand, & Huguet, 2019). An increased impairment of executive attention or cognitive control has been found when the co-present individuals are consider a threat that needs to be monitored (Huguet, et al., 2014), or when they represent an evaluative potential (Belletier et al., 2015). In the context of the dual attention task, a task partner deploying covert attention towards the same spatial location one is focusing on could feel more threatening or could imply a higher evaluative potential than a partner attending to a different location. This would direct more executive resources towards monitoring the co-attending task partner, reducing the attention capacity (that would be otherwise used for other activities like the task at hand) in respect to the condition in which this task partner does not share the locus of attention. The reduction in the attention capacity for the attention shared condition could potentially explain the dual attention effect. Investigating how the information processing stages in the brain (e.g., event-related potentials) are influenced by sharing or not the attended spatial locations with another individual could shed more light in this regard. This could for instance, show whether the dual attention effect is the result of reduced sensory processing, or top-down driven.

The shared attention literature (see Shteynberg, 2015, 2018 for a review) has provided evidence showing that sharing attention towards the same objects or tasks with other individuals might elicit a more elaborate processing of the co-attended objects/tasks, enhancing general performance. Although the shared attention literature has not tested the specific role the attended spatial locations may play on shared attention, given their evidence/proposals one would be inclined to predict a performance increase when co-attending to a spatial location with another person in the dual attention task. However, this was not the case, and instead, the attention performance dropped when the attentional locus was shared by the dyad (compared to the attention not shared condition). Shteynberg (2015) proposed tasks may not always be the object of shared attention. He suggested that under some circumstances (e.g., if the other person is not working on the task, but just watching one’s performance), this focus could shift from one’s task to one’s performance, leading to increased resources deployed to monitor one’s performance, potentially driving an increase in arousal/anxiety (e.g., Geen, 1991). However, as discussed by Shteynberg (2015), and in consonance with the classic social facilitation literature (e.g., Zajonc, 1965), an increased drive or arousal would lead to enhanced performance for easy tasks, like the one here performed, which was not the case.

Alternatively, it could be suggested that sharing the attended side of the screen could have induced a social-loafing-like effect (Latané, Williams, & Harkins, 1979), with participants putting less effort in the task, compared to the attention not shared condition. However, social-loafing effects are usually obtained in groups when one expects other participants in the group to put the effort necessary to complete (or perform better) the task at hand, or when one’s contribution cannot be tracked/identified by the rest (Karau & Williams, 1993). In the case of the dual attention paradigm, participants were performing independent go/no-go tasks, responding to different shapes. One participant responded to the large circles, and the other participant responded to the large squares. Therefore, given the independent nature of the task, reducing one’s endeavour owing to others’ extra effort potential was not an option. Moreover, sharing the attended side of the screen could increase the probability of having one’s performance/effort monitored by the task partner, making it less likely for loafing to appear, if compared to the not shared condition. Considering these arguments, a social loafing account for the current results becomes unlikely.

The positive correlation between AQ scores and the dual attention effect is rather surprising. Higher autistic traits are generally associated to deficits in social information processing (Frith, 2001; Frith & Frith, 2010), and individuals with autism exhibit severe impairments in the ability to spontaneously represent other's minds (Senju, Southgate, White, & Frith, 2009). In this line, and of high relevance for the current research, it has been shown that the collective perspective induced by shared attention, and the associated general performance enhancement, are not present in individuals with high autistic traits (Skorich, Gash, Stalker, Zheng, & Haslam, 2017; Shteynberg, 2018; but see Sebanz, Knoblich, Stumpf, & Prinz, 2005, for evidence for unaltered co-representation abilities in individuals with autism). Therefore, considering the above-mentioned research, and in opposition to the current finding, a negative (or null) correlation between AQ and the dual attention effect would have been expected (i.e., the higher the participant's autistic traits, the more the interpersonal influence in the task is reduced). Nonetheless, anticipating the outcome of follow-up experiments reported in this thesis, the present correlation was not further replicated (see Experiment 3). Thus, it is possible that this positive correlation actually represented a spurious finding.

It is important to mention that controlling eye-movements is always recommended in attention-related experiments to avoid any possible confound from foveal processing of the stimuli, which is faster and more precise than the peripheral non-foveal counterpart (Chica, Martín-Arévalo, Botta, & Lupiáñez, 2014). In the current experiment, even if participants were instructed to keep a constant central fixation, eye movements were not monitored and therefore the central fixation could not be taken for granted. Given that the attention/trial validity employed (e.g., 75% of the target stimuli appearing at the attended side of the screen) biases attention towards the instructed attended hemifield, even if participants performed systematic eye movements towards the locations were the stimuli were displayed, this would only be reflected in overall changes in the reaction times distributions, but would not affect the attention effect modulations here reported. Alternatively, if participants instead looked directly at the attended location, RT to valid trials would be much faster, and RT to invalid trials much slower, respect to a central fixation scenario, leading to a larger attention effect . This attention effect could only be stronger for the shared condition (i.e., when the two persons' tasks were inducing gaze shifting in the same direction) than for the notshared condition. In this case, gaze shifting would induce a larger attention effect for the shared condition, a prediction contradicting the current results. Following these arguments, even if eye-movements were not monitored, it seems unlikely for eye-movements to explain the dual attention effect.

Finally, it could be argued that the dual attention effect was not interpersonally driven, but instead elicited by intrinsic properties of the task at hand (e.g., the unbalanced target distribution between shared and not shared conditions). Participants were instructed to sustain their attention covertly towards one side of the screen for a whole experimental block. To encourage these attentional shifts, the distributions of valid and invalid trials was biased (i.e., 75% valid trials vs. 25% invalid). Although the overall stimuli distribution was balanced in the task (i.e., the probability of having an stimulus at any side of the screen was matched for every condition) (see *Figure 3*), the distribution of target stimuli was not. For the attention shared condition 75% of the targets for both participants appeared at the same location (i.e., 75% of the large circles and 75% of the large squares), the one co-attended by the dyad. For the attention unshared condition instead, one location (e.g., left) displayed 75% of the targets for one participant (e.g., large circles), while the other location (e.g., right) showed 75% of the targets for the remaining participant (e.g., large squares). This is a necessary feature of a sustained attention task, essential to maintain the sustained attention behaviour. However, it could be the case that when performing the two-person version of the task, the unbalanced target distribution induced an unwanted bias in attention, responsible for the reported effect (i.e., the reported reduction in the attention effect for the attention shared condition). To explore whether the bias in the distribution of targets elicited the dual attention effect, Experiment 2[2] was conducted.

2.2. Experiment 2

Experiment 2 examined whether the attention performance reduction in Experiment 1 was merely driven by the unbalanced distribution of the target shapes. In Experiment 2, participants completed a *solo version* of the *dual attention paradigm*. The only change from Experiment 1 is that participants performed the task alone. The notation used for the levels of the attention sharing factor was kept as in Experiment 1 (i.e., attention “shared” and “notshared”) to facilitate comparisons. However, given that the individuals were performing in isolation, these levels do not refer to actual sharing (or not) of the attended spatial locations.

2 I would like to thank Steven Tipper for his valuable comments and suggestions in this regard while we discussed the current work at the BACN 2017 annual scientific meeting.

If the effect obtained in Experiment 1 was elicited by the intrinsic difference in the distribution of targets across attention sharing conditions (i.e. probability properties), we would expect Experiment 2 to replicate this effect. If instead, the difference in the attention effect across sharing conditions varies from Experiment 1 (two-persons) to Experiment 2 (single-person), we could argue that this difference is indeed interpersonally driven or elicited by the social context of the task. This difference across experiments, however, could come in one of two forms. On one hand, it could be possible that when performing the *solo version* of the task, the unbalanced distribution of targets (large circles/squares) causes an even smaller attention effect for the attention “shared” condition (i.e., the condition with a 75% probability of targets displayed at the attended location) than in the “unshared” one, compared to the dyadic setting. This would suggest that sharing the attended locations with another individual actually enhanced the attention performance measured when completing the task in isolation. On the other hand, it could happen that when comparing the two experiments, Experiment 2 shows a weaker reduction in the attention effect for the “shared” vs “notshared” condition than Experiment 1. This scenario would provide additional evidence to suggest that the attention reduction in dyads sharing the locus of attention (reported in Experiment 1) was indeed a social effect interpersonally driven.

2.2.1 Method

2.2.1.1 Participants

Forty-three students participated in Experiment 2 (25 females; 34 right-handed; M_{age}= 22.51, SD_{age}= 4.45). They reported normal or corrected-to-normal vision. All participants provided written informed consent to take part in the study, and were given either one (1) course credit or eight pounds (£8) for their participation.

2.2.1.2 Design

The current experiment employed the same 2X2 factorial design than Experiment 1, where Attention (attended vs. unattended location) and “Sharing” (“attention shared” vs. “notshared”) were manipulated within-subjects. Here however, participants performed the task in isolation. Therefore, the “Sharing” factor did not reflect “attention sharing conditions” in relation to a task partner. Instead, this factor reflected the unbalance distribution of target shapes across these attention sharing conditions in the original dual attention paradigm (see the introductory section above). To allow for comparisons across experiments, Experiment Type (Solo vs. Dyad) was subsequently included as between-subjects factor.

2.2.1.3 Materials and procedure

The experimental set-up was identical to that of Experiment 1, except that participants performed the task individually (instead of as dyads) sitting centrally to the monitor. The trials that belonged to a task partner in Experiment 1 did not require any responses. As in Experiment 1, a total of 1280 were presented. From these, 320 required a response from the participant (i.e., go-trials). No questionnaires were employed given that this was not a social task.

2.2.2 Results

Five participants were excluded from statistical analysis due to accuracies below 75% per design cell. The remaining 38 participants (23 females; 30 right handed; M_{age}= 23.05, SD_{age}= 4.22) were analysed. The analyses were the same as those being employed in Experiment 1.

2.2.2.1 Accuracies

Participants showed a high performance in the task ($M_{ACC,\ Exp2}$ = 97.38 %, 95% CI [96.04, 98.73]). Mean accuracies (see *Table 4*) were analysed as in Experiment 1. No statistically significant effect was obtained with the ANOVA, while the percentile bootstrap method on 20% trimmed means revealed a significant interaction Attention x Sharing, $\hat{\psi}$ = -1.08 [-1.91, -0.31], p = .006, and no significant main effects.

Table 4. Mean accuracies (with SD) for Experiment 2. Mean accuracies are here presented as percentage of correct responses.

Experimental Condition			
Notshared		**Shared**	
Attended	**Unattended**	**Attended**	**Unattended**
97.06(4.92)	97.76(4.53)	97.61(4.52)	97.11(4.04)

2.2.2.2 RTs

RTs for go-trials were analysed. Only trials with correct responses (97.4%) were considered. The same criterion of 2.5-MAD for outlier removal was applied, leading to rejection of 5.1% of the remaining data.

Mean RTs (see *Figure 5* and *Table 5*) were analysed the same way as in Experiment 1. The condition names were kept identical to those in Experiment 1 to allow comparisons. The 2-way-within-subjects ANOVA yielded a significant interaction of Attention x Sharing, $F(1, 37) = 33.74$, $p < .001$, $\eta^2_G = 0.025$. This interaction, however, shows the opposite pattern to that of Experiment 1. The attention effect was significant for the attention shared condition (M = 33 *ms*, 95% CI [25.78, 41.12]), $F(1, 37) = 78.05$, $p < .001$, $\eta^2_G = 0.082$, and was not significant for the unshared condition (M = -1 *ms*, 95% CI [-8.3, 6.29]), $F(1, 37) = 0.07$, $p = .780$. The main effect of Attention was also significant ($M_{attended}$ = 441 *ms*, 95% CI [423.28, 458.37]; $M_{unattended}$ = 457 *ms*, 95% CI [439.67, 474.42]), $F(1, 37) = 54.20$, $p < .001$, $\eta^2_G = 0.022$, while the main effect of Sharing was not, $F(1, 37) = 0.30$, $p = .585$.

Consistent with these, the percentile bootstrap on 20% trimmed means showed a significant interaction Attention x Sharing, $\hat{\psi}$ = -31 [-42.14, -22.01], $p = 0$, a significant main effect of attention, $\hat{\psi}$ = 29 [16.83, 42.74], $p = 0$, and a not significant main effect of Sharing, $\hat{\psi}$ = -6 [-17.12, 6.68], $p = .354$. In addition, after computing the attention effect, the attention effect compared across Sharing conditions yielded a BF10 = 1651410, representing “extreme” evidence for model with the effect of Sharing (equivalent to the interaction Attention x Sharing before the attention effect was calculated), relative to the model without it, given the data.

As in Experiment 1, post-hoc simple main effects analysis examined the effect of “Sharing” separately for the each of the Attention conditions. Both the ANOVA and the percentile bootstrap on 20% trimmed means yielded a significant difference between the participants RTs to attended locations across Sharing conditions, $F(1, 37) = 15.51$, $p = < .001$; $\hat{\psi}$ = 14.34 [7.62, 20.11], $p = 0$. Participants responded faster to stimuli displayed at the attended locations in the “shared” condition (compared to the "unshared" scenario) (see *Table 5*). In addition, *RTs* to unattended locations were slower for the "shared" condition than for the "unshared" one, $F(1, 37) = 18.73$, $p = < .001$, $\eta_G^2 = 0.03$; $\hat{\psi} = -16.79$ [-26.97, -6.95], $p = 0$.

Table 5. Mean RTs in ms (with SD) for Experiment 2.

Experimental Condition			
Notshared		**Shared**	
Attended	**Unattended**	**Attended**	**Unattended**
449(55)	448(50)	433(54)	466(58)

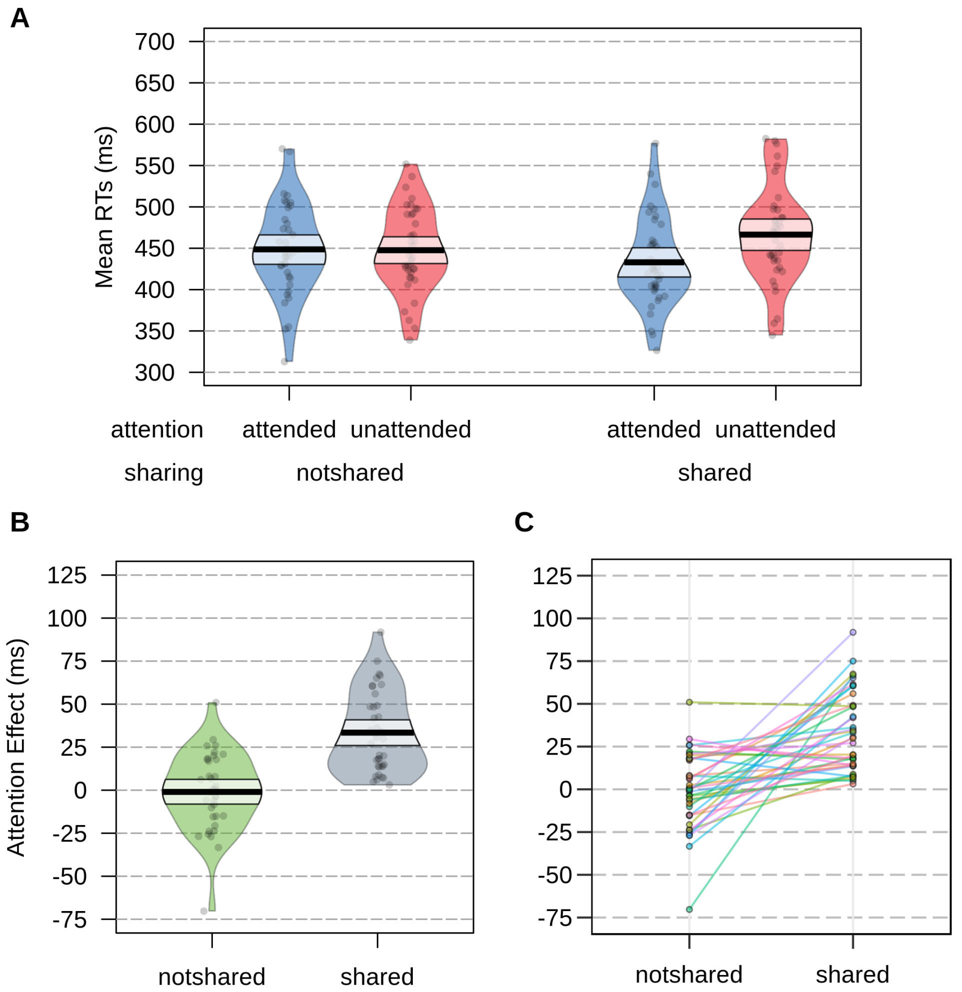


Figure 5. Results Experiment 2. A) Mean RTs as a function of attention (attended, unattended), and sharing (shared, not shared) conditions. The group means for each condition are displayed with 95% confidence intervals (CIs) **B)** Mean attention effect across sharing (shared, not shared) conditions. The attention effect is calculated as the difference between the mean RTs for the unattended condition and the mean RTs for the attended condition (i.e., $M_{AttEffect} = M_{unattended} – M_{attended}$). Means are displayed with 95% CIs. Contraty to the result in Experiment 1, here, a reduction in the attention effect was obtained when the dyad did not shared the attended spatial locations (i.e., a

negative dual attention effect). **C)** Stripchart showing the attention effect for each participant across sharing conditions. Lines were drawn to join paired observations. Out of the 38 participants analysed, 32 (~ 84.2% of the group) showed an effect in the same direction than the group mean (i.e. a reduction of the attention effect for the attention not shared condition).

2.2.3 Comparing Experiments 1 and 2

2.2.3.1 Accuracies

Due to high performance obtained in both experiments ($M_{ACC, Exp1}$ = 97.1 %, 95% CI [95.74, 98.54]; $M_{ACC, Exp2}$ = 97.38 %, 95% CI [96.04, 98.73]), accuracies were not further analysed.

2.2.3.2 RTs

Mean RTs (see *Figure 6*) from Experiments 1 and 2 were submitted to a 3-way mixed ANOVA, with an added factor Experiment Type (Solo vs. Dyad) as between-subject factor. The ANOVA showed a significant main effect of Experiment Type, $F(1, 76) = 4.59$, $p = .035$, $\eta_G^2 = 0.052$, due to slower responses in Experiment 2 (M = 449 *ms* , 95% CI [431.62, 466.25]) than in Experiment 1 (M = 425 *ms*, 95% CI [409.57, 439.78]). The main effect of Attention was also significant, $F(1, 76) = 120.56$, $p < .001$, $\eta_G^2 = 0.041$, reflecting a typical attention effect. Mean RTs were faster for the attended condition (M = 423 *ms*, 95% CI [412.32, 434.01]), than for the unattended one (M = 444 *ms*, 95% CI [433, 455.76]). The two-way interactions Attention x Sharing ($F(1, 76) = 9.47$, $p = .003$, $\eta_G^2 = 0.003$) and Attention x Type ($F(1, 76) = 7.33$, $p = .008$, $\eta_G^2 = 0.003$) were also significant (but see the results with the robust test). More importantly, a significant three-way interaction was obtained, $F(1, 76) = 42.87$, $p < .001$, $\eta_G^2 = 0.013$, suggesting that the modulation in the attention effect (calculated as: $M_{AttEffect} = M_{Unattended} – M_{attended}$) across attention sharing conditions (i.e. the dual attention effect; $M_{dualAttEffect} = M_{AttEffect,Unshared} – M_{AttEffect,Shared}$) varies between experiments (i.e., depending on whether the participants performed the two-person version of the paradigm, $M_{dualAttEffect,Exp1}$ = 12 *ms*, 95% CI [4.09, 20.75], or the solo version $M_{dualAttEffect, Exp2}$ = -34 *ms*, 95% CI [-46.47, -22.44]). Indeed, these showed opposite patterns across experiments. No other main effect nor interaction were significant.

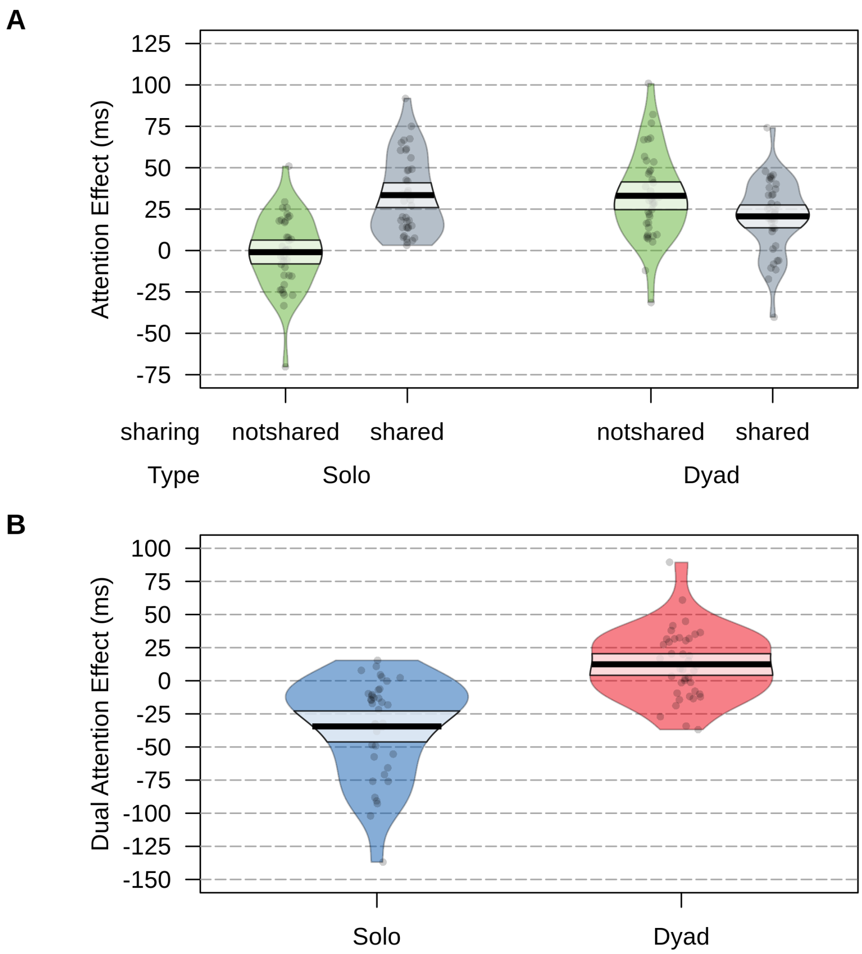


Figure 6. Experiment 2 (Solo) vs. Experiment 1 (Dyad). A) Mean attention effect across sharing conditions (shared, not shared) and Experiment Type (Exp2: Solo, Exp1: Dyad). The attention effect is calculated as the difference between the mean RTs for the unattended condition and the mean RTs for the attended condition (i.e., $M_{AttEffect} = M_{unattended} - M_{attended}$). Group means are displayed with 95% confidence intervals (CIs). **B)** Mean dual attention effect as a function of Experiment Type (Exp2: Solo, Exp1: Dyad). The dual attention effect is calculated as the difference between the mean attention effect for the notshared condition and the mean attention effect for the notshared condition (i.e., $M_{dualAttEffect} = M_{\text{AttEffect, unshared}} - M_{\text{AttEffect, shared}}$). Group means are displayed with 95% confidence intervals (CIs). Experiments 1 and 2 showed dual attention effects in opposite directions. Positive in Experiment 1, negative in Experiment 2.

The between-within-within percentile bootstrap on 20% trimmed means yielded a significant main effect of Experiment Type, $\hat{\psi}$ = 108 [22.9, 197], *p* = .014, a significant main effect of Attention, $\hat{\psi}$ = -86 [-105, -68.1], *p* = 0, a significant interaction Attention x Sharing, $\hat{\psi}$ = 25 [9.21, 43], *p* = .001, and a significant interaction Type x Attention x Sharing, $\hat{\psi}$ = 46 [31.3, 64.6], *p* = 0. With this method, the interaction Attention x Type was not significant, $\hat{\psi}$ = 18 [-0.681, 35.3], *p* = .059. After computing the attention effect and submitting it to the Bayes factors analysis, the 2-way interaction Type x Sharing yielded BF10 = 2056690, suggesting "extreme" support for the model with the interaction, relative to the model without it, provided the data.

2.2.4 Discussion

The modulation of the attention effect across attention sharing conditions varied between Experiment 1 (two-persons) and Experiment 2 (single-person), showing a completely opposite pattern across experiments. The attention effect was enhanced for the "shared" condition in the solo version, and reduced for the (actual) Shared condition in the two-person task, relative to the "not shared" situation. As a reminder, the notation used for the levels of the attention sharing factor was kept as in Experiment 1 (i.e., attention "shared" and "notshared") to facilitate comparisons, but participants in Experiment 2 actually performed in isolation (not in dyads). Given that the social context of the task (i.e., the presence of the task partner and his/her task) was the only difference across experiments, Experiment 1 and 2 together provide strong evidence suggesting that the attention performance reduction in dyads sharing the locus of attention previously obtained (Experiment 1) was indeed interpersonally driven.

Overall responses were faster when performing in dyads (Experiment 1: *M* = 425 *ms*, *95% CI* [409.57, 439.78])) than when performing alone (Experiment 2: *M* = 449 *ms* , *95% CI* [431.62, 466.25]). This is an expected result considering the presence of a second participant in Experiment 1. It has been shown that the mere presence of other individuals influences one's performance, facilitating easy tasks, like the one here performed (i.e., social facilitation; Zajonc, 1965). Facilitation in this case was reflected as faster responses for the dyadic version of the task, compared to the solo version. The current finding could also be examined/elucidated from the perspective of the Shared attention theory (Shteynberg, 2015). According to this theory, an enhanced general performance is achieved when co-attending to the same tasks with other individuals. Following this, improved performance would be expected when sharing attention to the task with the task partner, which was indeed the case here given the shorter reaction times observed in the two-persons setting, compared to the responses in isolation. However, as argued when discussing the results of Experiment 1, the shared attention theory cannot account for the dual attention effect obtained in the dyadic setting.

In opposition to the pattern obtained in Experiment 1, in Experiment 2 the attention effect was present for the attention “shared” condition, and disappeared for the “notshared” case. One key difference between the dual attention paradigm (in this case the, the solo-version of the task) and the classic sustained attention paradigm is that the dual attention task compensates for the intrinsic imbalance in the distribution of target shapes (see *Figure 3*) by modifying the distribution of non-target stimuli. 75% of the non-target shapes appeared at the unattended side, while 25% were displayed at the attended location (i.e., 1:3 ratio, valid non-targets:invalid non-targets). In this way, the probability of having a stimulus appearing at either side of the screen (valid or invalid) was matched across experimental block (this also meant that the overall stimulus distribution across attention sharing conditions was balanced, avoiding confounding the results in the dyadic task -but this is less important for the current argument). This however, is not part of the typical sustained attention paradigm (in which, the attended side would contain more stimuli overall), and would greatly reduce the attention bias towards the attended side. The go/no-go task requires participants to actively process each stimulus and decide whether they should respond. If visual processing is needed for both the attended and unattended locations (with the same probability), attention will not be effectively allocated in benefit of the attended location. This would suggest a null attention effect and no difference across attention sharing conditions, which was not the pattern here obtained.

Nonetheless, regardless of this modification, Experiment 2 inherited the unbalanced distribution of target stimuli employed in Experiment 1. If a participant in Experiment 2 was assigned a target shape (e.g., the large circles), this meant that in the “shared” condition the large circles had a 75% probability of appearing at the attended location, and 25% probability of appearing at the unattended one. Since the remaining large shapes (i.e., the large squares) were the targets for the second participant in Experiment 1 (the second participant was absent in the current experiment), they shared these probabilities (i.e., the large squares also had a 75% probability of being displayed at the valid side, and 25% for the invalid one). This unbalanced distribution of large stimuli could explain the obtained results if the possibility of a goal-directed/contingent bias in the task (Folk, Remington, & Johnston, 1992) is considered. Participants were instructed to respond to the “large” stimuli with their assigned shape (e.g., respond to the large circles). This means that “large” was one of the relevant target features. Therefore, participants were constantly looking for large shapes when completing the task. Given the unbalanced probability of shapes with this target feature (i.e., large) across conditions, performance could be boosted (or not) by following/attending to these probabilities (i.e., the bias present in the distributions of large stimuli). A 75% probability of large shapes at the attended side helped performance and biased attention towards this side, generating a typical attention effect. Instead, a 50% probability did not help in completing the task, and did not induce a bias in attention, resulting in a null attention effect. This outcome mirrors the pattern obtained in the current Experiment.

Interestingly, the same pattern would be observed if participants performing in isolation were in charge of the full dual attention task (i.e., if they had to respond to both large circles and large squares), or if participants co-represented the full task set in the two-person version (as in Knoblich & Sebanz, 2006). In both cases, the task would become a classic single person visuospatial sustained attention paradigm, with a 75% probability of valid trials for the “shared” contidion, and 50% probability of valid trials for the “notshared” one. The outcome would be, once more, a typical attention effect for the “shared” condition, and a null effect for the “notshared” scenario. The fact that this pattern was already present in Experiment 2 (solo version), but not in Experiment 1 (two-person version), discards a full co-representation account as the underlying cause behind the dual attention effect observed in the dyadic setting. That is, the dual attention effect in Experiment 1 cannot be explained by individuals mentally representing the full task set, including both their own task and the one assigned to the task partner. Still, given that the only difference between Experiments 1 and 2 was the presence of the task partner and his/her task, the opposite patterns across experiments suggest that the dual attention effect was induced by this difference. In other words, the effect was interpersonally driven by the task partner. Therefore, the potential explanations discussed around the social-cognitive origin of the dual attention effect (in Experiment 1) still hold after considering the outcome of Experiment 2. Experiment 2 however, adds to the understanding of the dual attention effect by ruling out the unbalanced distribution of target stimuli in the task as the reason behind this effect. Finally, the findings here presented showed the “baseline” performance in the dual attention task when no social factor is involved (i.e., solely driven by the statistical properties of the stimuli), suggesting that the social effect is thus (if taken together with Exp1's results), inhibitory in nature.

2.3. Experiment 3

Collectively, the previous findings reported in this Chapter suggest the contribution of two different processes in the dual attention task. A stimulus driven contribution (Exp 2), related to the statistical properties inherent to the behavioural task (i.e., the unbalanced distribution of target shapes across attention sharing conditions), and a social component (Exps 1), related to the interpersonal influence observed when performing the task in dyads, measured as a reduction in attention performance (i.e., a smaller attention effect) when sharing the attended locations with the task partner (i.e., the dual attention effect). Given that attention has evolved, in response to the limited processing capacity of the human brain, as a way to select relevant information from an information-rich environment (Pashler, Johnston, & Ruthruff, 2001), it becomes crucial to understand whether the contribution of the above-mentioned social process is affected by loading attentional resources (e.g., in this case, increasing the perceptual load) to one's own task (the non-social effect). This idea will be addressed in the current experiment, and, as will be argued in the following paragraphs, would provide important insights on whether there is a stand-alone social mechanism underlying dual attention.

It has been proposed that early attention selection is modulated by perceptual load (i.e., by the attentional resources demanded by a task at perceptual-level processing stages), and that in consequence, successfully ignoring distractors (i.e., irrelevant information) depends on the processing demands of the task at hand (Load theory; Lavie, 1995, 2005, 2010; Lavie & Tsal, 1994; see also Murphy, Groeger, & Greene, 2016). Evidence for this came originally from distractor interference paradigms, like the flanker task (Eriksen & Eriksen, 1974). In this kind of tasks, in order to respond to the target stimuli (e.g., responding to the identity of a letter out of two possibilities), irrelevant stimuli need to be inhibited (e.g., additional letters surrounding the target), and the degree of processing linked to the task-irrelevant distractor(s) is measured by the interference it/they provoke when responding to the task-relevant information. This interference is measured behaviourally in terms of RTs and accuracies changes depending on the congruency of the information provided by the interfering stimuli (e.g., Eriksen & Eriksen, 1974; Lavie & de Fockert, 2003). In support for the load theory, it has been shown that increasing the perceptual load (e.g., by increasing the number of items surrounding the target) reduces the processing of the irrelevant items and their interference in the task (e.g., Lavie & de Fockert, 2003; see also Benoni, 2018; Murphy et al., 2016). Similarly, in the context of visuospatial attention, it has been shown that increasing the perceptual load to foveal targets in spatial cueing paradigms derives in a decreased early-sensory-processing neural response to parafoveally presented task-irrelevant stimuli (i.e., as reflected by the P1 event-related component), respect to a low-perceptual-load condition (Handy et al., 2001). In line with the load theory, this outcome has been taken to suggest that an increased load for target stimuli reduces the residual attentional capacity available to process task-irrelevant information, and that the effect of load on attentional selection occurs at early visual/sensory processing stages in the brain (Handy & Mangun, 2000; Handy et al., 2001). The lack of modulation by perceptual load instead (i.e., if the interference, process or effect under investigation remains unaffected under an increased perceptual load), has been taken to suggests that the interfering information employs resources from a separate process/capacity (Benoni, 2018; Murphy et al., 2016).

An important question would then be whether the social modulation of attention, measured by the dual attention effect, is also sensitive to perceptual load. This question was examined in the current experiment. Experiments 1 and 2 suggested that the dual attention effect (i.e., the reduced attention effect when the dyad shared the attended spatial locations in the dual attention task, compared to the condition in which their locus of attention differed) is driven by interference in relation to the task partner and his/her task (even if the specific cause of this interference is not yet well understood). According to the load theory (Lavie, 2005, 2010; see also Benoni, 2018; Murphy et al., 2016) the perceptual load associated to the performed task (here the sustained attention task with a size discrimination) determines to which extent distracting information is processed (here social information related to the task partner and her task). An increased perceptual load should exhaust attentional resources, reducing or hindering the interference from the distractor. Applied to the current context, the load theory would predict that the increased task/perceptual load employed in the current manipulation would reduce the interpersonal influence measured in the dual attention task (i.e., should reduce the size of the dual attention effect). This outcome would also suggest that the socially-driven inhibition effect is happening at the same time with the sensory-level attention (or the dual attention effect is taking place via the sensory attention itself) (Handy & Mangun, 2000; Handy, Soltani, & Mangun, 2001). If instead, the dual attention effect persists (i.e., remains unaffected) under high perceptual load, this would suggest the existence of separate processes associated with the results from Experiment 2 (i.e., non-social, stimulus driven), and the results of Experiment 1 (i.e., the social effect). In this line, it could be the case that, in the context of dual attention, the distractor (i.e., the other person and his/her task) receives resources from a different process (e.g., top-down control), or from a special/separate attentional capacity. This idea seems plausible considering that a special module dedicated to the processing of social information separate from perceptual input has been previously suggested (Emery, 2000; Ristic et al., 2005; Wei, Rushby, & De Blasio, 2019). Moreover, considering that higher level processes are less likely to be affected by an increased perceptual load (Handy & Mangun, 2000), this result (i.e., the persistence of the dual attention effect under an increased perceptual load) could be also taken to suggest that the dual attention effect takes place at a higher level information processing stage in the brain.

Visual perceptual load is typically manipulated in one of three ways: by modifying the number of items simultaneously displayed during the task (aka. set-size manipulation), by varying the task to be performed, or by manipulating the similarity between target and non-target items (Murphy et al., 2016). The present experiment opted for the third method to avoid any potential low-level visual interaction among concurrently displayed stimuli (e.g., in set-size manipulations it has been argued that the effect of perceptual load could be also accounted for by competition between the distractor and the simultaneously presented stimuli, or dilution of the distractor by the presence of the additional items; Benoni, 2018). Hence, in the current experiment, perceptual load was heightened by increasing the similarity between target and non-target shapes in the dual attention task, making the size discrimination task more difficult to perform (see Handy & Mangun, 2000, for a similar manipulation).

2.3.1 Method

2.3.1.1 Participants

Forty-eight students (24 dyads) participated in Experiment 3 (34 females; 44 right handed; M_{age}= 23.27, SD_{age}= 5.12). They reported normal or corrected-to-normal vision. All participants provided written informed consent to take part in the study, and were given either one (1) course credit or eight pounds (£8) for their participation. Participants in the same dyad reported not having a close relationship.

2.3.1.2 Design

The present experiment employed the same 2X2 factorial design than Experiment 1, where Attention (attended vs. unattended location) and Sharing (attention shared vs. notshared) were manipulated within-subjects, and the participant's reaction times (*RTs*) and accuracies (percentage of correct responses) to the target stimulus were the dependent variables. In the current experiment however, the perceptual load was increased respect to the original paradigm presented in Experiment 1, making the task harder to perform. To allow for comparisons across experiments, Experiment Type (Exp1:Easy vs. Exp3:Hard) was subsequently included as between-subjects factor.

2.3.1.3 Materials and procedure

The experimental set-up, task, and trial sequence were as in Experiment 1. The only difference was the increased similarity between the size of the target and non-target shapes. The size of the large (target) stimuli was set to 4.57° x 4.57°, while the small (non-target) stimuli size was 3.97° x 3.97°. Therefore, non-targets in Experiment 3 were about 75% of the size of the target shapes, while non-targets in Experiment 1 were about 30% of the size of the targets.

As in Experiment 1, participants responded to several questionnaires. Before the computer-based trials, participants completed the IND-COL scale (Singelis, Triandis, Bhawuk, & Gelfand, 1995). After completing the computer-based section of the experiment, they filled in the AQ (Baron-Cohen et al., 2001), and the STAI (Spielberger, 2012).

2.3.2 Results

Three participants were excluded from statistical analysis due to accuracies below 50% per design cell. This new threshold was set to guarantee that participants had an appropriate number of trials per condition to be analysed given the increased difficulty of the task (respect to Exp1). The data from the remaining 45 participants (33 females; 41 right handed; M_{age}= 23.47, SD_{age}= 5.22) were analysed. The data were analysed as in Experiment 1, including the correlations between the questionnaires scores (I.e.., the scores from the *Individualism-Collectivism sub*scales, the *Autism-spectrum Quotient*, and the *State-Trait Anxiety Inventory*) and the dual attention effect (i.e., $M_{dualAttEffect} = M_{\text{AttEffect, unshared}} – M_{\text{AttEffect, shared}}$).

2.3.2.1 Accuracies

Mean accuracies (M_{ACC} = 83.41%, *95%CI* [80.71, 86.11]) were lower than in Experiment 1 (see the section "Comparing Experiments 1 and 3"), and were analysed as in the previous experiments. That is, mean accuracies (see *Table 6*), were submitted to a 2x2 repeated-measures ANOVA with Attention (attended vs. unattended) and Sharing (shared vs. unshared) as within-subjects factors. The ANOVA revealed a significant interaction Attention x Sharing, $F(1, 44) = 10.52$, $p = .002$ ($M_{\text{diff\_shared}}$ = 1.35 %, 95% CI [-0.88, 3.58]; $M_{\text{diff\_unshared}}$ = -3.2 %, 95% CI [-5.51, -0.89]; $M_{\text{diff}} = M_{\text{unattended}} – M_{\text{attended}}$). The same significant interaction was obtained using the within-within robust ANOVA on 20% trimmed means with the percentile bootstrap method, $\hat{\psi}$ = 4.63 [1.57, 7.65], p = .003. The main effects of Attention and Sharing were not significant.

Table 6. Mean accuracies (with SD) for Experiment 3. Mean accuracies are here presented as percentage of correct responses.

Experimental Condition			
Notshared		**Shared**	
Attended	**Unattended**	**Attended**	**Unattended**
84.93(9.77)	81.72(12.42)	82.81(9.42)	84.17(11.17)

2.3.2.2 RTs

The data for the go-trials from the remaining 45 participants were kept for further analysis. Trials with correct responses were analysed (83.4%). Outliers were removed using a threshold of 2.5 times the Median Absolute Deviation (MAD). This eliminated 5.0% of the remaining data.

Experiment 3 replicated the effects obtained in Experiment 1 (see *Figure 7* and *Table 7*). The ANOVA yielded a significant main effect of Attention ($M_{attended}$ = 479 *ms*, 95% CI [464.56, 494.36]; $M_{unattended}$ = 504 *ms*, 95%5 CI [488.02, 519.35]), $F(1, 44)$ = 89.20, $p < .001$, η^2_G =0.048, and a significant interaction Attention x Sharing, $F(1, 44)$ = 10.58, $p = 0.002$, η^2_G =0.005. As in Experiment 1, there was a reduction in the attention effect for the attention shared condition (M = 17 *ms*, 95% CI [9.85, 23.28]), F(1, 44) = 24.70 , $p < .001$, η^2_G =0.027, compared to the unshared condition (M = 32 *ms*, 95% CI [24.58, 39.2]), F(1, 44) = 77.28, $p < .001$, η^2_G =0.070. The main effect of Sharing was not significant, $F(1, 44) = 3.63$, $p > .063$.

The within-within robust ANOVA with bootstraping on 20% trimmed means showed a significant main effect of attention, $\hat{\psi}$ = -45 [-57.26, -34.92], $p = 0$, a not significant main effect of Sharing, $\hat{\psi}$ = 13 [-1.71, 30.61], $p = .079$, and a significant interaction Attention x Sharing, $\hat{\psi}$ = -17 [-24.95, -7.75], $p < .001$.

Moreover, for the Bayes Factors Analysis the attention effect was calculated and compared across Sharing conditions, yielding a BF10 = 13.76. This represents “strong” evidence for the model with the Sharing effect (or the Attention x Sharing interaction, before computing the attention effect), relative to the model without it, given the data.

Post-hoc simple main effects analysis examined the effect of Sharing separately for the each of the Attention conditions. *RTs* to attended locations were not statistically different across sharing conditions, $F(1, 44) = 0.20$, $p = .654$ (ANOVA); $\hat{\psi}$ = -3.41 [-12.75, 7.39], $p = .536$ (percentile bootstrap on 20% trimmed means). In contrast, *RTs* to unattended locations were significantly faster when dyads shared the locus of attention in the task, than when the attentional locus was notshared, $F(1, 44) = 8.56$, $p = .005$, η^2_G = 0.03; $\hat{\psi}$ = 15.13 [5.29, 26.18], $p = .001$.

2.3.2.3 Correlation Analysis

None of the correlations between the questionnaires scores and the dual attention effect was significant (see *Table 8*).

Table 7. Mean RTs in ms (with SD) for Experiment 3.

Experimental Condition			
Notshared		**Shared**	
Attended	**Unattended**	**Attended**	**Unattended**
481(57)	513(60)	478(48)	495(51)

Table 8. Correlations in Experiment 3. The scores from the *Individualism-Collectivism (IND-COL)* subscales, the *Autism-spectrum Quotient* (*AQ)*, and the *State-Trait Anxiety Inventory (STAI)*, were correlated to the dual attention effect ($M_{dualAttEffect} = M_{\text{AttEffect, unshared}} - M_{\text{AttEffect, shared}}$). Spearman's correlations and Bayes Factors are reported in all cases.

Individualism-Collectivism (IND-COL) *(N*=44*)*	-
Combined Collectivism (HC+VC)	r_s = 0.153, *p* = .320, BF10 = 0.503
Horizontal Individualism (HI)	r_s = 0.096, *p* = .536, BF10 = 0.441
Vertical Individualism (VI)	r_s = 0.106, *p* = .494, BF10 = 0.444
State-Trait Anxiety Inventory (STAI) *(N*=34*)*	r_s = -0.085, *p* = .631, BF10 = 0.440
State Anxiety (Y1)	r_s = -0.106, *p* = .533, BF10 = 0.463
Trait Anxiety (Y2)	r_s = -0.105, *p* = .531, BF10 = 0.479
Autism-spectrum Quotient (AQ) *(N*=42*)*	r_s = 0.030, *p* = .849, BF10 = 0.345

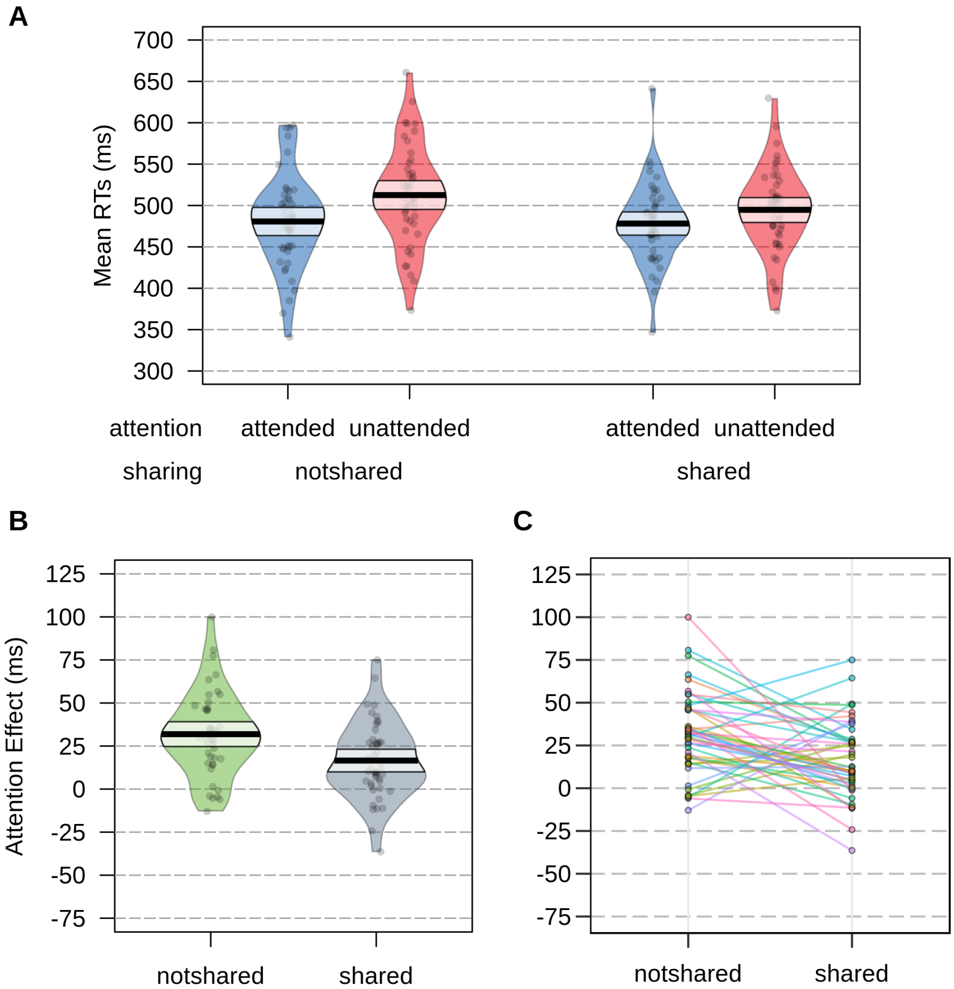


Figure 7. Results Experiment 3. A) Mean RTs as a function of attention (attended, unattended), and sharing (shared, not shared) conditions. The group means for each condition are displayed with 95% confidence intervals (CIs) **B)** Mean attention effect across sharing (shared, not shared) conditions. The attention effect is calculated as the difference between the mean RTs for the unattended condition and the mean RTs for the attended condition (i.e., $M_{AttEffect} = M_{unattended} – M_{attended}$). Means are displayed with 95% CIs. The dual attention effect introduced in Experiment 1 (i.e., the reduction in the attention effect when the dyad shared the attended spatial locations) was replicated in Experiment 3. **C)** Stripchart showing the attention effect for each participant across sharing conditions. Lines were drawn to join paired observations. Out of the 45 participants analysed, 33 (~ 73.3% of the group) showed an effect in the same direction than the group mean (i.e. a reduction of the attention effect for the attention shared condition).

2.3.3 Comparing Experiments 1 and 3

2.3.3.1 Accuracies

To compare Experiment 1 and Experiment 3, mean accuracies were submitted to a 3-way Mixed ANOVA, adding Experiment Type (Exp1:Easy vs. Exp3:Hard) as between-subject factor. This yielded a significant main effect of Experiment Type, $F(1, 83) = 77.00$, $p < .001$, $\eta_G^2 =0.399$, given that participants performed better in Experiment 1 (M = 97.14 %, *95%CI* [95.74, 98.54]) than in Experiment 3 (M = 83.41 %, *95%CI* [80.71, 86.11]). The robust test (*'bwwmcppb'* function; Wilcox, 2012) supported this result, $\hat{\psi}$ = 56.2 [43.3, 68.2], $p = 0$. In addition, the classic 3-way ANOVA also yielded a significant interaction Attention x Sharing, $F(1, 83) = 13.25$, $p < .001$, $\eta_G^2 =0.002$, but this was not the case for the robust test, $\hat{\psi}$ = 8.78 [-0.34, 12.9], $p = .060$. Regarding this disparity, it should be mentioned that robust methods are generally preferred (and their results trusted more) over classic statistical tests, especially when addressing accuracies data, known to violate the normality assumption associated to the latter (Field & Wilcox, 2017).

2.3.3.2 RTs

As for the accuracies data, mean RTs in Experiment 1 and Experiment 3 (see *Figure 8*) were submitted to a 3-way Mixed ANOVA, adding Experiment Type (Exp1:Easy vs. Exp3:Hard) as between-subject factor. A significant main effect of Experiment Type, $F(1, 83) = 39.78$, $p < .001$, $\eta_G^2 =0.290$, was obtained due to shorter RTs for Experiment 1 (M = 425 *ms,* 95% CI [409.57, 439.78]) than for Experiment 3(M = 492 *ms*, 95% CI [476.5, 506.63]). The typical main effect of Attention was significant ($M_{attended}$ = 446 *ms*, 95% CI [433.98, 457.85]; $M_{unattended}$ = 470 *ms*, 95% CI [458, 482.94]), $F(1, 83) = 158.168$, $p < .001$, $\eta_G^2 =0.057$, as well as the interaction Attention x Sharing ($M_{AttEffect, shared}$ = 17 *ms*, 95% CI [10.8, 22.46]; $M_{AttEffect, unshared}$ = 32 *ms*, 95% CI [26.58, 39.39]), $F(1, 83) = 19.22$, $p < .001$, $\eta_G^2 =0.004$. The interaction Type x Sharing was also significant (but see the results with the robust test), $F(1, 83) = 4.33$, $p = .041$, $\eta_G^2 =0.004$. The 3-way interaction Type x Attention x Sharing was not significant

($M_{dualAttEffect, Exp1}$ = 12 *ms*, 95% CI [4.09, 20.75]; $M_{dualAttEffect, Exp3}$ = 15.33, 95% CI [5.83, 24.83]), $F(1, 83) = 0.21$, $p > .65$, nor any of the remaining effects.

The between-within-within percentile bootstrap on 20% trimmed means showed a significant main effect of Experiment Type, $\hat{\psi}$ = -284 [-355, -205], $p = 0$, a significant main effect of Attention, $\hat{\psi}$ = -101 [-121, -83.2], $p = 0$, and a significant interaction Attention x Sharing, $\hat{\psi}$ = -24 [-39.5, -9.33], $p = .001$. The interaction Type x Sharing was not significant (unlike the result yielded by the parametric test), $\hat{\psi}$ = -24 [-49.2, 0.78], $p = .057$, nor the interaction Type x Attention x Sharing, $\hat{\psi}$ = 2.5 [-12.6, 18.3], $p = .734$. Indeed, for this interaction (Type x Sharing, after computing the attention effect), Bayes factors, BF10 = 0.243 suggested “moderate” support for the model without the interaction, which is 4.11 times more likely than the model with it, given the data.

2.3.3.3 Correlation Analysis

Given their “statistical equivalence”, the data from Experiments 1 and 3 were combined into a single dataset, and correlations between the questionnaires scores (I.e., the scores from the IND-COL subscales, the AQ, and the STAI) and the dual attention effect (i.e., $M_{dualAttEffect} = M_{\text{AttEffect, unshared}} – M_{\text{AttEffect, shared}}$) were run on the pooled data. However, none of the performed correlations was significant (see *Table 9*). Importantly, the correlation between AQ and the dual attention effect obtained in Experiment 1 was not replicated in the current Experiment, nor when combining the data from Experiments 1 and 3, and is therefore, no further discussed.

2.3.4 Discussion

A clear effect of load on task performance was obtained, both in terms of accuracy and RTs. Participants in the current experiment (Exp 3) showed a reduced accuracy, and slower responses respect to the low-load/easy version of the task (Exp1). Large effect sizes were obtained in both cases. More importantly, the dual attention effect (Exp1) was replicated here, adding important confidence regarding the robustness and consistency of this effect, and this interpersonal influence measured in the dual attention task was not modulated by an evidently more difficult size discrimination between target and non-target stimuli in the task. In other words, the dual attention effect remained unaffected under an increased perceptual load.

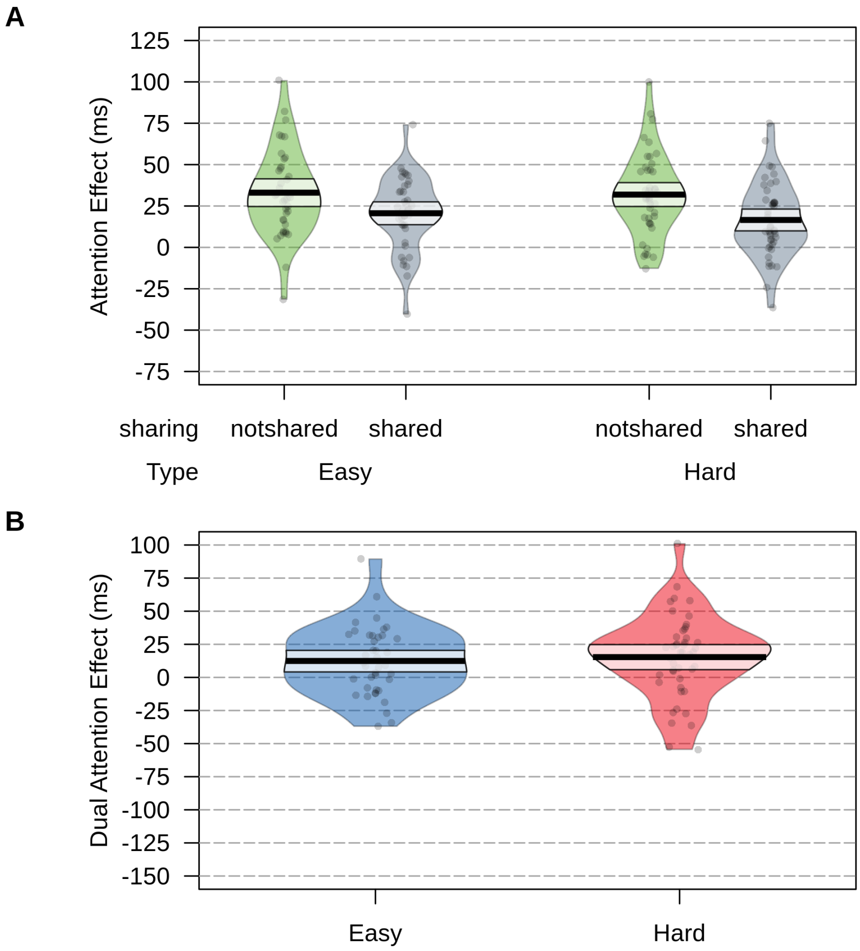


Figure 8. Experiment 1 (Easy) vs. Experiment 3 (Hard). A) Mean attention effect across sharing conditions (shared, not shared) and Experiment Type (Exp1: Easy, Exp3: Hard). The attention effect is calculated as the difference between the mean RTs for the unattended condition and the mean RTs for the attended condition (i.e., $M_{AttEffect} = M_{unattended} – M_{attended}$). Group means are displayed with 95% confidence intervals (Cis). **B)** Mean dual attention effect as a function of Experiment Type (Exp1: Easy, Exp3: Hard). The dual attention effect is calculated as the difference between the mean attention effect for the notshared condition and the mean attention effect for the notshared condition (i.e., $M_{dualAttEffect} = M_{\text{AttEffect, unshared}} – M_{\text{AttEffect, shared}}$). Group means are displayed with 95% confidence intervals (CIs). Increasing the task load in Experiments 3 did not modulate the attention effect. This persistence of the effect under high load, suggest it is automatic, at least in one dimension: efficiency.

Table 9. Correlations in Experiment 1&3 (Combined). The scores from the *Individualism-Collectivism (IND-COL)* subscales, the *Autism-spectrum Quotient* (*AQ)*, and the *State-Trait Anxiety Inventory (STAI)*, were correlated to the dual attention effect ($M_{dualAttEffect} = M_{\text{AttEffect, unshared}} – M_{\text{AttEffect, shared}}$). Spearman's correlations and Bayes Factors are reported in all cases.

Individualism-Collectivism (IND-COL) *(N*=84*)*	-
Combined Collectivism (HC+VC)	r_S = 0.132, p = .230, BF10 = 0.498
Horizontal Individualism (HI)	r_S = 0.107, p = .332, BF10 = 0.535
Vertical Individualism (VI)	r_S = 0.059, p = .592, BF10 = 0.308
State-Trait Anxiety Inventory (STAI) *(N*=73*)*	r_S = -0.022, p = .852, BF10 = 0.271
State Anxiety (Y1)	r_S = -0.056, p = .630, BF10 = 0.299
Trait Anxiety (Y2)	r_S = 0.002, p = .985, BF10 = 0.266
Autism-spectrum Quotient (AQ) *(N*=81*)*	r_S = 0.154, p = .169, BF10 = 0.469

The fact that the dual attention effect persisted under an increased perceptual, suggests that the related behavioural attention performance reduction measured in dual attention, may not be taking place via a sensory-level attentional process, but that instead, the interfering inhibitory process (likely social, and related to the task partner) employs resources from a separate capacity, or is processed at a different stage (Handy & Mangun, 2000; Handy, Soltani, & Mangun, 2001). As introduced above, this may be plausible considering that a special module dedicated to the processing of social information separate from perceptual input has been previously suggested (Emery, 2000; Ristic et al., 2005; Wei, Rushby, & De Blasio, 2019). However, additional research is needed to investigate if separate processing module/capacity is indeed behind the dual attention effect. In addition, considering that higher level processes are less likely to be affected by an increased perceptual load (Handy & Mangun, 2000), the previous result could also suggest that the dual attention effect takes place at a higher level information processing stage in the brain. These conclusions however, cannot be confirmed based exclusively on the aforementioned behavioural data. Additional research is needed to investigate if separate processing modules are indeed behind the dual attention effect. Electroencephalographic (EEG) recordings could be employed for this purpose (see Lopes da Silva, 2013, for a review), and were indeed investigated in Chapter 4.

Alternatively, it could be argued that the presence of the dual attention effect in the high load condition is actually the result of an ineffective perceptual load manipulation. The load theory literature has not yet defined/agreed a clear way to operationalise perceptual load (Benoni, 2018; Murphy et al., 2016), making it hard to solve with full certainty the circularity implied in this case (i.e., whether the load manipulation was unsuccessful or whether separate processes contribute to dual attention) (Benoni, 2018; Murphy et al., 2016). However, a failed manipulation is unlikely in the current experiment given the large effect sizes obtained for both accuracies and reaction times (described above). Moreover, the perceptual load manipulation was mainly employed to engage more resources within the task. Thus, the accuracy itself (even if it was high) would not indicate that the manipulation failed (i.e., participants could still have completed the task with a lot more effort). In addition, it could be argued that the sustained attention paradigm has a ceiling/floor effect, making it impossible for RTs at attended locations to be faster, or those at unattended locations to be slowed down more. This would impede testing the modulation by task load. However, there is evidence suggesting that they both (i.e., RTs for attended and unattended locations) can be further changed, at least in the cued version of the task (e.g., Lee, Lee, & Boyle, 2009). Considering this evidence, it seems unlikely that ceiling and/or floor effects could have accounted for the current results. Furthermore, following the load theory, the impaired distractor processing elicited by the perceptual load manipulation would be expected to derive in a reduction in the dual attention effect. Thus, a smaller dual attention effect would have been here obtained (hypothesised above), respect to the original task presented in Experiment 1. Yet, the opposite pattern was present. The dual attention effect was qualitatively (i.e., non statistically different) stronger for the high (Exp3) vs. low (Exp1) perceptual load version of the task. This pattern provides additional confidence towards the absence of a perceptual load effect in the current experiment.

Individual differences have been shown to modulate the effects of load (Murphy et al., 2016). In the current experiment individual differences were not assessed. Therefore, it could be the case that the perceptual load manipulation did not affect every participant in exactly the same way. A potential way of fitting the task to each participant could be to use a stair-case-like procedure (Dixon & Mood, 1948; see also

Read, 2015), adapting the task load according to a specific individual performance threshold. After obtaining the individual load parameters (in this case the similarity between targets and non-targets) for the respective thresholds, the task load could be decided for the dyad accordingly (e.g., using the average load for the pair, using the lowest one, or using different load settings for the two participants in each pair; see also Handy & Mangun, 2000, who set the accuracy to be always 75% for each participant by changing the stimuli online). This would reduce the inter-subject variability in the perceptual load manipulation, and may provide more accurate insights about the role of perceptual load in the dual attention effect, if any.

Considering the efficiency dimension of automaticity[3] (Murphy et al., 2016), and in line with the load theory (Lavie, 2005, 2010), the obtained indifference of the dual attention effect to the presence of perceptual load could also suggests that, at least for this dimension (i.e., efficiency), the dual attention effect can be considered automatic. According to the automaticity framework, the presence of interference from distractors in the high-load scenario indicates that the interfering process does not require attentional resources to be deployed and is therefore efficient/automatic (Lavie, 2005, 2010). In this line, the current findings may also add to the body of literature suggesting automaticity as a core/pervasive feature of social-cognitive processes (Bargh et al., 2012; Bargh & Williams, 2006). Stereotyping (Bargh & Williams, 2006), implicit theory of mind (Schneider, Lam, Bayliss, & Dux, 2012), imitative behaviours (Ramsey, Darda,

3 Traditionally, psychology has followed a two-process theory of information processing (Shiffrin & Schneider, 1977). Emphasizing a distinction between processes said to be “automatic” (or occurring without attention), and those considered exactly the opposite, also known as “controlled” (i.e., requiring attention to be performed) (Melnikoff & Bargh, 2018; Moors, 2016; Moors & De Houwer, 2006; Shiffrin & Schneider, 1977). Following this view, if a process is said to be “automatic”, it is also considered efficient, unintentional, uncontrollable, and unconscious, all together. In a similar way, if a process is said to be “controlled”, it is also assumed to be inefficient, intentional, and conscious. In the two-process theory, these features are used as synonyms, without distinction, keeping a two-sided view of automaticity in relation to information processing. This binary view however, has been extended, and automaticity nowadays is considered as (or encouraged to be studied as) a multi-component/multi-dimensional construct (Melnikoff & Bargh, 2018; Moors & De Houwer, 2006), or as an umbrella term comprising at least the above-mentioned features. Given that these features do not actually align, they should ideally be studied independently (Melnikoff & Bargh, 2018). In this line, a process or behaviour could be considered automatic in terms of intentionality if it is not dependent on a goal or previous instruction (aka., unintentional). It can be considered automatic in terms of consciousness if it occurs subliminally, without conscious awareness (aka., unconscious). It can be considered automatic in terms of controllability if it can not be stopped or top-down modulated after being triggered (aka., uncontrollable). Or it could be considered automatic in terms of efficiency if it persist under perceptual/cognitive load (aka., efficient)

& Downing, 2019), and gaze-induced joint attention (Frischen et al., 2007), are processes said to be deployed in an automatic manner. The former two (i.e., stereotyping and implicit theory of mind) have been shown to occur unintentionally (although inefficiently) (Gilbert & Hixon, 1991; Schneider et al., 2012), while the later two (i.e., imitative behaviours and gaze-triggered attention shifts) are both unintentional and efficient behaviours (Frischen et al., 2007; Ramsey et al., 2019; Xu et al., 2011). It is important to note that both gaze-induced joint attention and the dual attention effect have been shown to be resistant to load. Perhaps these evidence together may indicate that efficiency is a characteristic of the information processing involved in co-attending to the world with other individuals. Investigating the remaining dimensions of automaticity in relation to the dual attention effect (i.e., whether the dual attention effect is occurs also in an unintentional, uncontrollable, and unconscious manner) could be an interesting avenue for future experiments.

2.4. Chapter summary

Chapter 2 investigated whether paying attention towards the same spatial location with another person modulates one's attention performance. To address this question, Experiment 1 proposed the dual attention paradigm. In this paradigm, two participants (i.e., a dyad sat side by side next to each other in front of a computer) performed independent visuospatial sustained attention tasks while sharing or not their attentional locus (i.e., the attended spatial locations). Contrary to the expectation, under this settings, attention performance (measured by the difference in RTs between attended vs. unattended conditions, aka., the attention effect) was reduced when the dyad deployed attention towards the same spatial locations, than when their locus of attention differed (aka. dual attention effect). This pattern was reversed when single participants performed the task in isolation (Experiment 2), suggesting that the reduction in the attention benefit was socially driven between individuals (interpersonally). This reversed pattern also suggested the existence of a stimulus driven (non-social) component in dual attention, related to the unbalanced distribution of target shapes across attention sharing conditions in the dual attention task. Experiment 3 provided two additional contributions. First, a replication of the dual attention effect, that increases the confidence on the robustness of the effect. Second, it showed that the dual attention effect remains unaffected under an increased perceptual load, suggesting that the related behavioural attention performance reduction may not be taking place via a sensory-level attentional process, but that instead, the interfering inhibitory process (likely social, and related to the task partner) may employ resources from a separate capacity, or is processed at a different stage (Handy & Mangun, 2000; Handy, Soltani, & Mangun, 2001). This idea however, needs to be followed up in future experiments (Chapter 4 addresses it by means of Electroencephalographic (EEG) recordings). Potential accounts for the dual attention effect were proposed, based on co-representing aspects of the partner's task (but a full co-representation account was discarded), or related to additional higher-order processing resources devoted to mentalising/monitoring individuals sharing one's visuospatial attentional locus.

3

DUAL ATTENTION EFFECT:

WITH WHOM? INVESTIGATING THE ROLE OF GROUP MEMBERSHIP AND REMOTE PRESENCE

The previous experiments investigated whether one's attention performance is modulated by paying attention towards the same spatial locations with another individual. The evidence there presented suggested a reduction in attention performance when a dyad shared their locus of attention in a *dual attention task*. This effect was termed *dual attention effect*. It is unclear though, under which circumstances would this interpersonal influence in attention performance occur. When exactly would a "co-attending" task partner affect one's attention performance? Would this effect differ depending on the social or physical closeness to the task partner? In a series of two experiments, the present chapter addressed the role of the social/physical closeness (in relation to the task partner) in dual attention. Specifically, Experiment 4 investigated the influence of the group membership attributed to the co-attending individual (in-group vs. out-group) (i.e., *social closeness*), while Experiment 5 examined the dual attention effect when the individuals in the dyad performed the dual attention task from remote locations (i.e., separate rooms), instead of sitting side by side physically next to each other (i.e., *physical closeness*).

3.1. Experiment 4

Recognizing strangers as belonging to one's social group may be a way to create a connection with them (Plötner, Over, Carpenter, & Tomasello, 2015; Tomasello, Melis, Tennie, Wyman, & Herrmann, 2012). Indeed, group membership has been shown to modulate the way we perceive others . A favouritism towards in-group members has been reported in literature (e.g., Brewer, 2007), with out-group members being, for instance, evaluated more negatively (Doise et al., 1972) or even dehumanized (Leyens et al., 2001) when compared to the in-group counterparts. Interestingly, this in-group favouritism has been shown even when groups are created based on minimal arbitrary criteria (minimal group paradigm; Tajfel, Billig, Bundy, &

Flament, 1971), like the participants' subjective colour preference (e.g., Shteynberg, 2009, 2010), their ability to estimate the number of dots presented on a screen (e.g., Stürmer, Snyder, Kropp, & Siem, 2006) or by simply making them wear coloured t-shirts (e.g., MacDonald, Schug, Chase, & Barth, 2013). Importantly, manipulating these minimal arbitrary cues was not only sufficient to elicit intergroup discrimination, but achieved this while excluding any influence from stereotypes, status, communication, or any history between the individuals involved (Dunham, 2018).

Categorising a task partner as belonging to one's group (or to a different one) has been shown to play an important role in joint performance. For instance, Shteynberg (2014, 2015) showed that sharing attention towards the same objects or tasks could enhance general performance, only if people believed they were simultaneously co-attending with similar others (i.e., in-group members). Similarly, the joint Simon Effect (JSE), a marker of task co-representation in dyads (Knoblich & Sebanz, 2006), was reduced, or even absent, when participants were performing with out-group individuals (e.g., McClung, Jentzsch, & Reicher, 2013; Müller et al., 2011) or when involved in a negative relationship with the co-actor (Hommel, Colzato, & van den Wildenberg, 2009). On the other hand, the interpersonal memory guidance of attention effect (i.e., the guidance of the spatial allocation of visual attention by the knowledge about the contents in a co-actor's working memory), was found to be reduced when performing with an in-group task partner (He, Lever, & Humphreys, 2011). Taken together these findings suggest that the social closeness to one's task partner (at least in terms of group membership) clearly affects the interpersonal influence occurring in joint performance. In this line, the present experiment examined whether social closeness, more specifically, the group membership status attributed to the task partner, also plays a modulating role in the interpersonal influence in attention performance measured by the dual attention effect. To avoid any influence from the history among individuals in the same dyad, stereotypes, status/hierarchies, or communication, a minimal group manipulation was implemented for this purpose.

The shared attention literature (see Shteynberg, 2015 for a review) has consistently employed a minimal group manipulation based on subjective colour preference (e.g., Shteynberg, 2010; Shteynberg & Galinsky, 2011; Shteynberg, Hirsh, Galinsky, & Knight, 2014; Shteynberg et al., 2014). In these studies, participants typically arrived in groups of three at the laboratory and performed relevant tasks on computers located in separate rooms. As part of the procedure, at the beginning of the experiment, they were instructed to pick one coloured avatar out of five possible choices displayed on the computer screen. In the following displays, together with the subsequent task's instructions, they saw either that the remaining participants chose the same coloured avatar they picked (in-group condition), or that they all chose different colours (out-group condition). This choice, however, was actually computer handled. Subsequently, they completed the remaining parts of the experiment that led to the main proposal of the Shared attention theory: Sharing attention with other individuals induces a "we-mode" that elicits a more elaborate processing of the co-attended objects or tasks. This "we-mode" state however, only holded when co-attending with individuals who, in these experiments, "picked" (or were believed to have picked) the same coloured avatar when commencing the experiment (i.e., similar others, or in-group members).

In the case of the joint action literature, to my knowledge, only two studies have addressed the role of group membership in joint performance by means of a minimal group manipulation. These were performed in the context of the joint Simon Effect (Iani, Anelli, Nicoletti, Arcuri, & Rubichi, 2011; McClung et al., 2013). Iani et al. (2011) employed a minimal group manipulation based on the results "derived from" a cognitive style test (actually computer handled). Participants were categorised as belonging to the "same" or a "different" cognitive style group, and then completed the typical joint Simon task (Iani et al., 2011). This manipulation however, did not yield an effect of group membership on joint performance (although an additional experiment showed an effect when manipulating competition). McClung et al. (2013) considered the weaknesses of Iani et al.'s (2011) study and followed up proposing a more robust/stronger minimal group manipulation. The categorisation induced by this manipulation successfully modulated task co-representation in the joint Simon Effect. The key improvements were the use of a cover story for the study (i.e., investigating the relationship between cognitive style and reaction times) and the use of badges that were given to the participants to be wore during the experiment. These badges reminded them about their group membership along the task.

The present experiment used a minimal group manipulation based on participants' subjective colour preference. Upon arriving at the laboratory, participants in a dyad were presented with two coloured bibs, one red and one blue (see *Figure 9*). They were asked to pick their favourite coloured bib and to wear it during the experiment. Participants sharing the subjective colour preference were expected to have a greater sense of connection with their experiment partner (i.e. same-group condition), while those choosing different bibs were expected to treat their partner as an out-group member (i.e. different-group condition). This manipulation was performed between-subjects. It is important to highlight that the manipulation here devised shares the key improvements proposed in McClung et al. (2013). Here, participants believed the study actually aimed at examining the influence of colour preference on attention performance (cover story), and they were given bibs to wear during the experiment (similar to the badges proposed by McClung et al. (2013). Therefore, these manipulations should elicit an intergroup categorisation effect of similar strength. Predicting the influence of this manipulation on the interpersonal influence measured by the dual attention task however, is not straightforward.

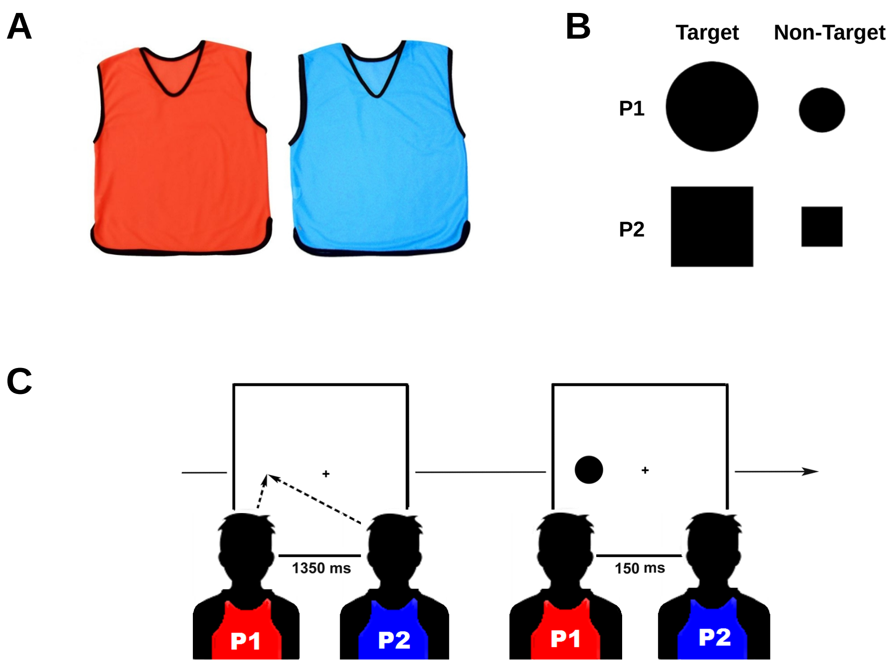


Figure 9. Dual attention task with a minimal group manipulation. A) Coloured bibs used for the minimal group manipulation. **B)** Stimuli employed. The task and stimuli in the current experiment are the same as in Experiment 1 (P1: Participant 1; P2: Participant 2). **C)** Participants in a dyad were asked to pick their favourite coloured bib and to wear it during the experiment. The subjective colour preference was considered as the minimal cue inducing an in-group (same colour preference) vs. out-group (different colour preference) membership status. Once the minimal group manipulation was completed, participants carried out the *dual attention task* described in Experiment 1. In the depicted example trial, both participants sustain attention towards the left side of the screen (attention shared condition), as indicated by the arrows.

As presented above, the Shared Attention theory (Shteynberg, 2015) posits that a more elaborate processing of co-attended objects/tasks holds only when these are co-attended with an in-group member. In addition, task co-representation, as measured by the joint Simon Effect (Knoblich & Sebanz, 2006; Sebanz, Knoblich, & Prinz, 2003) is reduced or absent when the co-actor is categorised as out-group (e.g., Aquino et al., 2015; McClung et al., 2013; Müller et al., 2011). The later result has been taken to suggest that performing with an out-group member could be equivalent to be performing in isolation (even if physically next to the task partner) (McClung et al., 2013). Taken together these previous findings could led to hypothesising that the dual attention effect would be enhanced (i.e., a stronger interaction Attention x Sharing) when completing the dual attention task with an in-group member (compared to the out-group scenario). This could be explained, for instance, by the greater competitive feeling experienced with out-group members (e.g., Kramer & Brewer, 1984; but note that He et al., 2014 did not show an effect of competition), which would lead to an increased focus in one's own task (e.g., de Bruijn, Miedl, & Bekkering, 2008), making participants use any relevant co-actor's task parameter only when considered as belonging to the same group. However, an alternative prediction is also plausible. The interpersonal memory guidance of attention is reduced among in-group dyads (He et al., 2011). Following this result, it could be possible to consider that also in dual attention settings, the interpersonal influence would be reduced among in-group members (i.e., a smaller interaction Attention x Sharing for the in-group condition). This could be explained for instance, by the higher levels of trust are experienced with in-group members (e.g., Brewer & Yuki, 2007). With higher levels of confidence/trust on the co-actor's performance, one would spend less cognitive resources tracking any relevant part of the partner's task/performance.

In the present study, interpersonal social influences (i.e., group membership effects) in attention performance (i.e., in dual attention) are investigated. This makes the current experiment closer to He et al. (2011) than to the joint performance research previously described (i.e., Aquino et al., 2015; McClung et al., 2013; Müller et al., 2011). Moreover, the fact that the dual attention effect was already present when participants performed the dual attention task with strangers (e.g., Experiments 1 and 3, described in Chapter 2) may be taken to suggest that dual attention and shared attention differ at least in the way they are modulated by social context (remember that the shared attention effect only holds when performing with in-group individuals; Shteynberg 2015, 2018). Considering these ideas, the current experiment was expected to follow He et al.'s (2011) results. That is, a reduced dual attention effect was predicted when performing with members of one's own group (i.e., a smaller interaction Attention x Sharing for the in-group condition).

3.1.1 Method

3.1.1.1 Participants

Ninety students (45 dyads) participated in this study (Experiment 4). All of them had normal (or corrected-to-normal) vision and normal colour vision. All participants provided written informed consent to take part in the study, and were given either one (1) course credit or eight pounds (£8) for their participation. Importantly, considering previous evidence suggesting that the interpersonal influence could be modulated by the nature of the relationship between individuals (e.g., He, Lever, & Humphreys, 2011), I decided to exclude those dyads reporting having a close relationship (i.e., friends and close friends). Eighteen participants (9 dyads) were not further considered for this reason. Therefore, the data from the remaining 72 participants[4] is presented below (63 females; 56 right handed; M_{age}= 20.34, SD_{age}= 2.96). From these, 44 participants picked the same coloured bib (in-group condition), and 28 chose different colours (out-group condition).

3.1.1.2 Design

The present study employed a 2x2x2 mixed-factor design, where Group membership (in-group vs. out-group) was manipulated between-subjects, and Attention (attended vs. unattended) and Sharing (attention shared vs. notshared) were manipulated within-subjects. The dependent variables were the participant's reaction times and accuracies (percentage of correct responses) to the target stimulus. The interpersonal influence in the dual attention task is reflected by a smaller attention effect (i.e., the RTs difference between valid and invalid trials) when a dyad shares the attended spatial locations in the task, compared with the situation in which their locus of attention differs (aka., dual attention effect). This effect is represented by a two-way interaction between the Attention and Sharing conditions. In the present study, this dual attention effect (i.e., in the interaction Attention x Sharing) was expected to differ

4 The conclusions here presented do not change if the full sample (90 participants) is considered/analysed.

depending on whether the task partner is categorised as an in-group or out-group member. Therefore, after adding group membership as a factor, the contrast of interest here was the (3-way) interaction Attention x Sharing x Group (in-group vs. out-group).

3.1.1.3 Materials and procedure

Upon arriving to the laboratory, the minimal group manipulation was performed. Participants in a dyad were presented with two coloured bibs, one red and one blue (see *Figure 9*). They were asked to pick their favourite coloured bib and to wear it during the experiment. Participants sharing the subjective colour preference were expected to have a greater sense of connection with their experiment partner (i.e. same-group condition), while those choosing different bibs were expected to treat their partner as an out-group member (i.e. different-group condition). This manipulation was performed between-subjects. The original purpose of the study was masked, making participants believe that examining subjective colour preference and its influence on attention was the main goal of the experiment. In fact, in line with this objective, the study was advertised with the title “Colour preference and attention performance in dyads”.

Once the minimal group manipulation was performed and the participants were wearing their respective favourite bib, the computer-based trials were carried out. The experimental set-up, task, and trial sequence were as in Experiment 1 (see *Figure 9*). As in Experiment 1, in the instruction phase, participants were told that it was essential for the study that they should not talk/communicate with each other during the experiment. E-prime 2.0 was used to program the experiment, control the experimental flow and record the responses.

Participants also responded to several questionnaires. Before the computer-based trials, they completed the Individualism-Collectivism scale (*IND-COL*; Singelis, Triandis, Bhawuk, & Gelfand, 1995) used to measure the degree to which participants saw their selves as members of a collective/social group or as independent selves. After the computer based-section of the experiment, participants completed the *Inclusion of the Other in the Self* scale (*IOS*; Aron, Aron, & Smollan, 1992), used to examine the subjective perceived closeness of the relationship between the experiment partners. Moreover, a 7-point-likert scale was used to assess the level of *Trust* regarding the partners’ ability to perform well during the task. Finally, a combined competitiveness questionnaire (He et al., 2014) was employed to measure if participants were engaged in competition during the experiment and how competitive they generally were. This questionnaire comprised 20 items. It was formed by the *Revised Competitiveness Index* (RCI: 14 items measuring the participants contentiousness and enjoyment of competition; Houston, Harris, McIntire, & Francis, 2002), the *competitiveness subscale of the Work and Family Orientation* Scale (WOFO: 5 items measuring the desire to outperform others and compete in interpersonal situations; Helmreich, 1978), plus an additional item 'I feel competitive in relation to other participants in this study' assessing the competitive feeling. Participants indicated to what extend they agreed with these statements in a five-point Likert scale.

3.1.2 Results

As mentioned above, from the initial 45 dyads, 9 were not included due to the nature of their relationship. For statistical analyses, three more participants were excluded due to accuracies below 75% in any design cell. Therefore, the data from 69 participants (26 in the out-group condition, 43 in the in-group condition) were considered for further analysis. All the analyses were performed using R (version '1.1.456') and RStudio (RStudio Team, 2016). As in Chapter 2, RTs were analysed employing classic ANOVAs, the percentile bootstrap method on 20% trimmed means (Wilcox, 2012), and Bayes factors. These were computed using the R packages '*ez'* (Lawrence, 2016), '*WRS2'* (Wilcox & Schönbrodt, 2014), and '*BayesFactor'* (Morey & Rouder, 2015), respectively.

3.1.2.1 Accuracies

Given the high performance showed by participants in this task, accuracies were not further analysed ($M_{ACC,\ ingroup}$ = 98.8 %, *95% CI* [98.45, 99.05]; $M_{ACC,\ outgroup}$ = 99 %, *95% CI* [98.75, 99.3]).

3.1.2.2 RTs

Only go-trials were considered. From these, only trials with correct responses were analysed (97.7%). Outliers were determined and removed using the 2.5-Median Absolute Deviation (MAD) method. This eliminated 4.8% of the remaining data.

I was interested in examining how the group membership modulates the attention effect in the sustained attention paradigm, while participants are either sharing or not the attended side of the screen. To investigate this effect, Reaction Times (RTs) data were submitted to a 2x2x2 Mixed-ANOVA with Group membership (in-group vs. out-group) as between-subjects factor, and Attention (attended vs. unattended) and Sharing (attention shared vs. notshared) as within-subjects factors (see *Figure 10* and *Table 10*). The 3-way-mixed-ANOVA yielded a significant main effect of attention, $F(1, 67) = 111.77$, $p < .001$, $\eta_G^2 = 0.048$. Overall responses were faster for stimuli appearing in the attended side of the screen ($M_{attended} = 432$ *ms*, *95% CI* [418.32, 445.1]) than for those displayed in the unattended side ($M_{unattended} = 458$ *ms*, *95% CI* [444.68, 471.13]). The analysis also showed a significant interaction Attention x Sharing, $F(1, 67) = 7.22$, $p = .009$, $\eta_G^2 = 0.002$, due to a smaller attention effect (i.e., $M_{AttEffect} = M_{unattended} – M_{attended}$) when participants were sharing the attended locations ($M_{attEffect, shared} = 22$ *ms*, *95% CI* [15.98, 27.74]), than when their locus of attention differed ($M_{attEffect, unshared} = 31$ *ms*, *95% CI* [24.84, 36.21]) (see *Figure 11*). No other main effect nor interaction was significant, including the 3-way interaction Group x Attention x Sharing ($M_{dualAttEffect, ingroup} = 6$ *ms*, *95% CI* [-1.88, 14.8]; $M_{dualAttEffect, outgroup} = 12$ *ms*, *95% CI* [0.29, 24.34]; $M_{dualAttEffect} = M_{AttEffect, unshared} – M_{AttEffect, shared}$), $F(1, 67) = 0.70$, $p = .405$ (see *Figure 12*).

The results yielded by the robust method and Bayes factors mirrored those presented above. The attention effect was computed beforehand and submitted to the between-within analysis with the percentile bootstrap method on 20% trimmed means (Between: Group, Within: Sharing). This showed a significant main effect of Sharing, $\hat{\psi} = 20$ [5.38, 32], $p = .008$, due to the difference in the attention effect across Sharing conditions. The main effect of Group was not significant, $\hat{\psi} = 3$ [-12.4, 21.3], $p = .595$, nor the interaction Group x Sharing, $\hat{\psi} = -6$ [-19.5, 7.32], $p = .376$. For this interaction (Group x Sharing, after computing the attention effect), Bayes factors, BF01 = 3.2 suggested “moderate” support for the model without the interaction, relative to the model with it, given the data.

For completeness, I present here the details of the 2-way interactions Attention x Sharing for each Group membership condition. For the In-group condition, the ANOVA yielded a non-significant 2-way interaction (Attention x Sharing), $F(1, 42) =$

2.44, p = .126, mirroring the result revealed by the percentile bootstrap method, $\hat{\psi}$ = -8.27 [-17.3, 1.63], p = .099. For the Out-group participants, the ANOVA showed a significant interaction Attention x Sharing, F(1, 25) = 4.45, p = .045, η^2_G =0.003, that was not supported by the result obtained with the robust method, $\hat{\psi}$ = -10.7 [-22.2, 1.38], p = .088.

3.1.2.3 Comparing questionnaires scores

I compared the scores from the *Individualism-Collectivism (IND-COL)* subscales, the *Combined Collectivism* scale, the *Inclusion of the Other in the Self (IOS)* scale, the *Trust* scale, and the *Combined Competitiveness* questionnaire across group membership conditions (in-group vs. out-group). Mann-Whitney U test were used for this purpose. However, none of the comparisons showed a statistically significant difference.

3.1.2.4 Correlation analyses

The scores from the *IND-COL* subscales, the *Combined Collectivism* scale, the *IOS* scale, the *Trust* scale, and the *Combined Competitiveness* questionnaire, were correlated to the dual attention effect derived from the participants reaction times (RTs). As in Chapter 2, the dual attention effect was calculated by subtracting the typical attention effect (i.e., $M_{AttEffect} = M_{unattended} – M_{attended}$) for the attention shared condition from attention effect for the unshared condition (i.e., $M_{dualAttEffect} = M_{\text{AttEffect, unshared}} – M_{\text{AttEffect, shared}}$). Spearman's correlations were employed in all cases. These are reported alongside Bayes Factors, obtained after running Bayesian correlations with the Jeffreys-beta prior (Ly, Verhagen, & Wagenmakers, 2016). None of the correlations was statistically significant (see *Table 11*).

3.1.3 Discussion

The purpose of the present study was to investigate the role of group membership on the *dual attention effect* (i.e., the reduced attention effect obtained when sharing the attended spatial locations with another person in the dual attention task, than when the locus of attention differed). A minimal group manipulation based on subjective colour preferences was employed for this purpose. Two main results deserve to be highlighted. First, the *dual attention effect* reported in Experiment 1, and already replicated in Experiments 3 and 4, was replicated one more time in the current study. This added confidence about the robustness of this effect. Second, the induced categorising of the task partner as in-group or out-group, did not modulate the *dual attention effect.*

Table 10. Mean RTs in ms (with SD) for Experiment 4.

	Experimental Condition			
	Notshared		Shared	
Group	**Attended**	**Unattended**	**Attended**	**Unattended**
In-group	431(56)	462(55)	438(58)	462(57)
Out-group	423(57)	453(61)	430(56)	448(57)

Table 11. Correlations in Experiment 4. The scores from the *IND-COL* subscales, the *Combined Collectivism* scale, the *IOS* scale, the *Trust* scale, and the *Combined Competitiveness* questionnaire, were correlated to the dual attention effect ($M_{dualAttEffect} = M_{\text{AttEffect, unshared}} - M_{\text{AttEffect, shared}}$). Spearman's correlations and Bayes Factors are reported in all cases.

Individualism-Collectivism (IND-COL) (*N*=69)	-
Combined Collectivism (HC+VC)	r_s = 0.096, p = .436, BF10 = 0.343
Horizontal Individualism (HI)	r_s = 0.127, p = .299, BF10 = 0.401
Vertical Individualism (VI)	r_s = 0.136, p = .264, BF10 = 0.442
Inclusion of the Other in the Self (IOS) (*N*=69)	r_s = -0.186, p = .126, BF10 = 1.280
Trust (*N*=69)	r_s = -0.153, p = .209, BF10 = 0.548
Combined Competitiveness (*N*=69)	r_s = -0.052, p = .673, BF10 = 0.304
Revised Competitiveness Index (RCI)	r_s = -0.083 , p = .499, BF10 = 0.324
Work and Family Orientation Scale (WOFO) - Competitiveness subscale	r_s = 0.026 , p = .832, BF10 = 0.276
Competitive feeling item	r_s = -0.098, p = .425, BF10 = 0.399

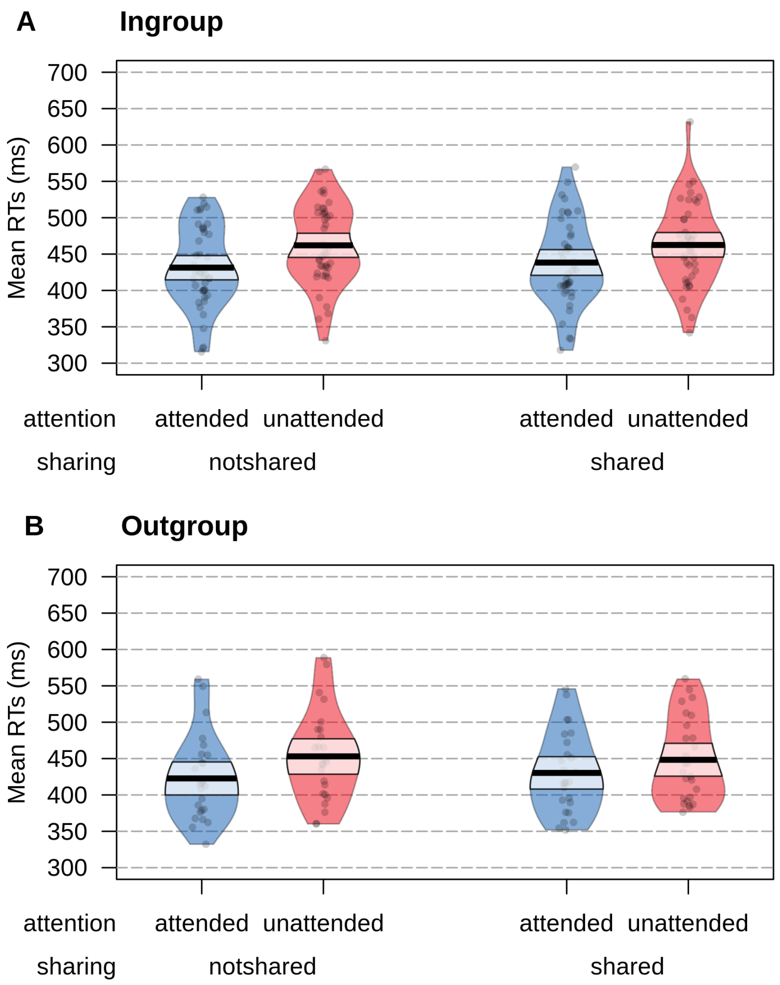


Figure 10. Mean RTs Experiment 4. Mean RTs are displayed as a function of group membership (A: in-group, B: out-group), sharing (shared, not shared) and attention (attended, unattended) conditions. The group means for each condition are displayed with 95% confidence intervals (CIs).

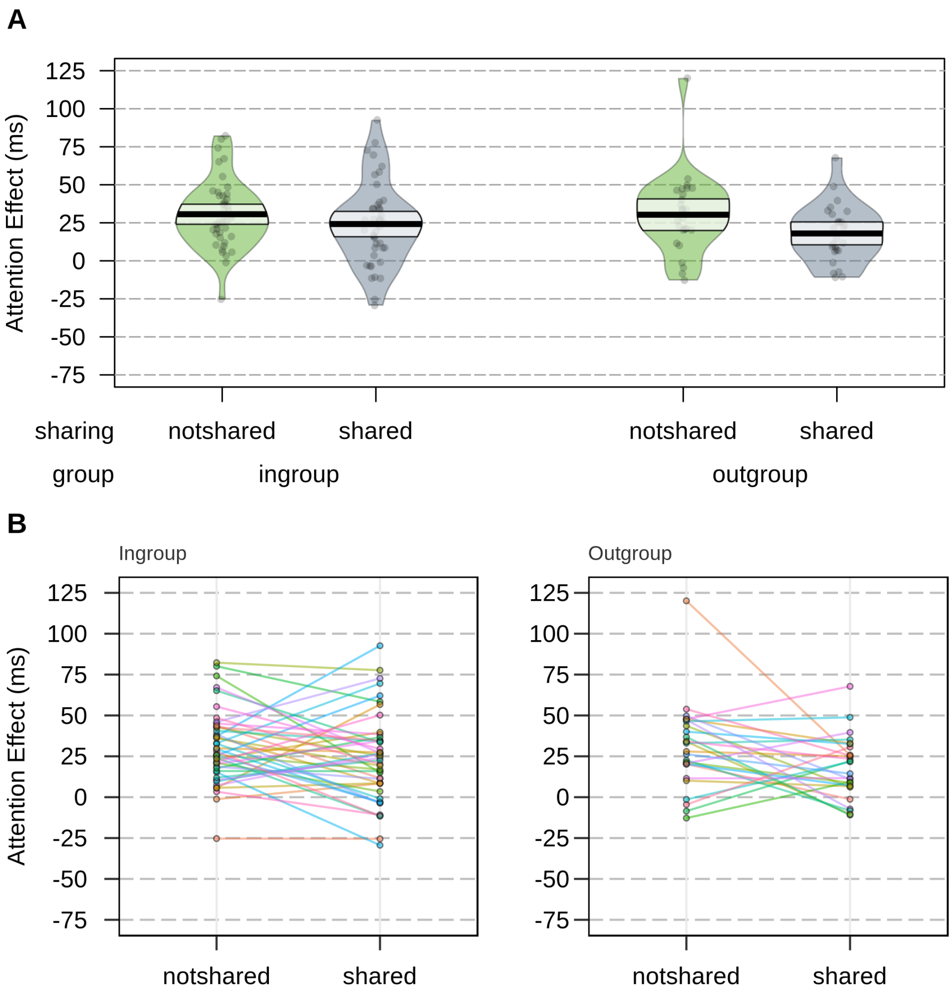


Figure 11. Attention Effect Experiment 4. A) Mean attention effect displayed as a function of group membership (in-group, out-group) and sharing (shared, not shared) conditions. The mean attention effect is calculated as the difference between the mean RTs for the unattended condition and the mean RTs for the attended condition (i.e., $M_{AttEffect} = M_{unattended} - M_{attended}$). Group means are displayed with 95% confidence intervals (Cis). **B)** Stripcharts showing the attention effect for each participant across sharing and group membership conditions. Lines were drawn to join paired observations. Out of the 43 participants in the out-group condition, 28 (~ 65.1% of the group) showed an effect in the same direction than the group mean (i.e. a reduction of the attention effect for the attention shared condition). From the 26 in-group participants, 17 (~ 65.4% of the group) showed and effect in this direction.

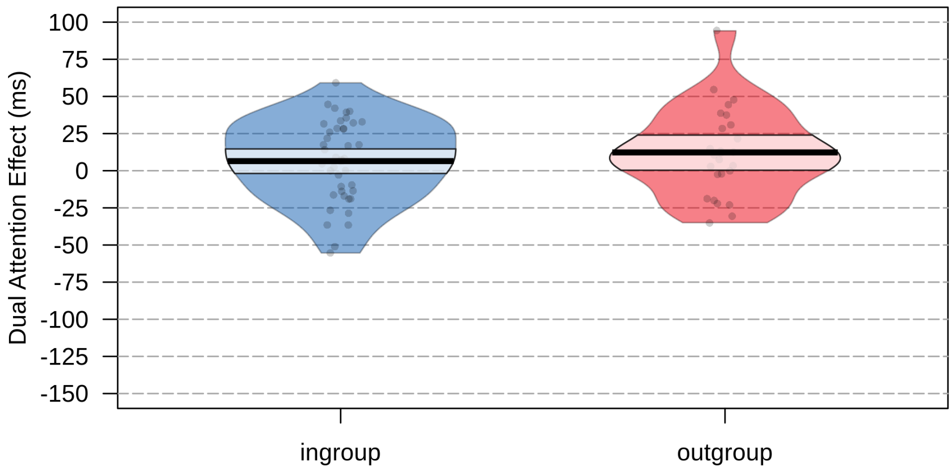


Figure 12. Dual attention effect Experiment 4. The mean dual attention effect is displayed as a function of group membership (in-group, out-group). This mean dual attention effect is calculated as the difference between the mean attention effect for the notshared condition and the mean attention effect for the notshared condition (i.e., $M_{dualAttEffect} = M_{\text{AttEffect, unshared}} – M_{\text{AttEffect, shared}}$). Group means are displayed with 95% confidence intervals (CIs).

The current experiment did not employ a clear manipulation check. Instead, self-reports were used to test the reported levels of trust, closeness, and competition across group membership conditions, which could reflect the effect of the minimal group manipulation. None of the questionnaires' scores differed when comparing the answers provided by in-group vs. out-group participants and therefore did not provide support for the success of the manipulation. Manipulation checks however, should be treated with caution, especially in the context of a minimal group manipulation. It is well known that when responding to questions, participants do not necessarily answer based on their actual state, but instead may reply based on the inferences they made about the task and the experimenter expectations (Hauser, Ellsworth, & Gonzalez, 2018). There are also social desirability biases, which can be prominent in self-reports (Fisher, 1993). More importantly, it has been shown that in most cases, under minimal group conditions, participants would not be sensitive to the effects of the manipulation in a conscious manner (Dunham, 2018). In this line, the null effect associated with self-reports in the current study does not necessarily mean that the minimal group manipulation here employed was not successful in eliciting the desired intergroup categorisation effect. Nonetheless, since the experiment did not employ a direct manipulation check, the absence of a group membership influence in dual attention settings could well be a failure of the current manipulation or an experimental effect. Considering this, the subsequent potential explanations should be treated with caution.

As discussed in the introductory section above, the design of the minimal group paradigm considered suggestions taken from manipulations used in the joint action (e.g., McClung et al., 2013; Müller et al., 2011) and shared attention literature. The current design used subjective colour preference as the minimal arbitrary criteria inducing the intergroup categorisation. This criteria proved successful in many studies in the shared attention literature (e.g., Shteynberg, 2010; Shteynberg & Galinsky, 2011; Shteynberg, Hirsh, Galinsky, & Knight, 2014; Shteynberg et al., 2014). In addition, the current experiment adopted the elements suggested by McClung et al. (2013) in order to shape a minimal group manipulation successfully moderating task co-representation in joint action settings. These key elements were the use of a cover story for the study (e.g., investigating the relationship between cognitive style and reaction times) and the use of badges to be wore by the participants during the experiment (to remind them about the group membership along the task). In our case, participants believed the study actually aimed at examining the influence of colour preference on attention performance (cover story), and they were given coloured bibs to wear during the experiment (similar to the badges mentioned above). Therefore, I consider the current manipulation to be as strong as the one proposed in McClung et al. (2003), in terms of eliciting the desired intergroup categorisation. This however, does not necessarily guarantee the success of the current manipulation in modulating attention performance in the dual attention task. Perhaps the dual attention effect is not shaped by group membership, or it could be the case that a stronger group membership manipulation is needed for this modulation to occur (see below).

It has been shown that jointly attending towards the same spatial locations with another person increases the reported levels of affiliation/bonding/closeness in relation to this co-attending person (Wolf, Launay, & Dunbar, 2016). Wolf, Launay and Dunbar (2016) went further by suggesting that joint attention could potentially elicit a minimal-group-like social categorization, with co-attending participants perceived as in-group members, and those with a disjoint attention (i.e., attention to a different spatial location) categorised as out-group members. If this is the case, it could be that in the dual attention task, the “categorisation effect” induced by shared/unshared attention could have overridden the actual minimal group manipulation, eliciting a stronger modulation of the sense of connection among participants than the one potentially induced by subjective colour preferences. Indeed, the shared/unshared blocks/conditions in the dual attention task could have acted as a live/online/automatic manipulation of the sense of connectedness within dyads. Given the importance it has for humans since early childhood (e.g., Mundy & Newell, 2007), the social relevance of co-attending towards the same spatial locations with other individuals would be more prominent than the attributed to colour preferences. Therefore, as mentioned above, it would not be surprising for the categorisation effect/impact of subjective colour preferences to be considerably smaller. However, this remains speculative and further research should address whether this is the case.

Whether an enhancement in the level of affiliation/bonding among participants (induced by joint attention, as suggested by Wolf et al., 2016) is behind the change in attention performance characterising the dual attention effect deserves further investigation. Wolf et al.(2016) examined the effect of joint attention in social bonding, but did not test attention performance changes in the co-attending individuals. A follow up experiment could employ the dual attention task for this purpose, using exclusively the *attention unshared* condition (excluding the shared one) together with a group membership manipulation. Under this scenario, following Wolf et al.(2016), I would hypothesise a reduction in the attention effect for participants in the in-group condition, compared to the out-group counterpart, similar to the one obtained in the original dual attention task when sharing (vs not sharing) the attended spatial locations. It is important to consider however, that in the current study, RTs when participants attended to different spatial locations did not differed across group membership conditions. Yet, it could have happened that when faced with two categorisation potentials (attention sharing vs. colour preference; participants were told about both at the beginning of the experiment), participants were more sensitive to the most relevant one (attention sharing), leaving the colour preference in a secondary role. Additional research is needed to shed light on these regard.

To date, only a few studies have reported evidence from minimal group manipulations in dyads where participants completed the subsequent tasks physically next to each other (e.g., McClung et al., 2013; Müller et al., 2011). In the past it was emphasised that anonymity (of the participants involved) was an essential part of a minimal group design, necessary for the manipulation to work (Tajfel et al., 1971). This previous limit however, has been thrown down by recent evidence showing successful manipulations in contexts where anonymity was not guaranteed (e.g., McClung et al., 2013). Till recently researchers file drawers have been filled with null results (Francis, 2012). It would be of paramount relevance for the field to open the "failures" to obtain minimal group effects in order to understand the actual consequences and limitations of these kind of manipulations (Dunham, 2018).

Although the proposed group membership manipulation did not alter the interpersonal influence in the dual attention task, it is plausible to consider that alternative manipulations of social context could be strong enough to actually moderate the effect of dual attention. In the joint action literature, experiments employing real groups involving race (e.g., black vs. white; Müller et al., 2011), and social status (e.g., albanian vs. italian participants; Aquino et al., 2015), successfully moderated co-representation levels in dyads. Positive/negative interdependence related manipulations also proved "successful" in this regard (He et al., 2011; Hommel et al., 2009). Social status was also shown to be a relevant aspect of social context modulating the interpersonal influence on basic cognitive processes related to spatial orienting (Gobel, Tufft, & Richardson, 2018). Therefore, follow-up experiments manipulating social context by any of these means (i.e., social status, racial groups, or interdependence/competition) could provide additional insights about the role of social context on the interpersonal influence represented by the dual attention effect.

To sum up, the current study left more open questions than answers in relation to the interplay between low-level cognitive processes (dual attention performance) and high-level social cognition (group membership). Additional research should shed more light in this regard. Importantly however, the results here presented constitute a further replication of the dual attention effect reported in Experiment 1, and already replicated on Experiment 3. These replications build up valuable confidence regarding the robustness of the dual attention effect.

3.2. Experiment 5

Previous experiments presented in this thesis (e.g., Experiments 1, 3 and 4) suggested that attending towards the same spatial location with another person affects one's attention performance (see Chapter 2). It is not clear however, whether this interpersonal influence on attentional processes persists while sharing the locus of attention with remotely located individuals. The current mass/social media ecosystem allows for this scenario to occur in a daily basis. Deploying attention towards the same spatial location in a screen while sharing content via social media, or while watching the same TV program with friends across the world, are a few examples where this remote influence may be possible. Thus, understanding whether this remote influence on attention actually occurs becomes timely relevant. In this line, Experiment 5 examined the dual attention effect when individuals in a dyad performed the dual attention task from remote locations (i.e., separate rooms), instead of sitting side by side physically next to each other.

Task co-representation effects have been shown to occur not only when performing with another person in one's peripersonal space (e.g., Sebanz et al., 2003), but also when performing with remotely present or imagined co-actors (e.g., Atmaca, Sebanz, & Knoblich, 2011; Ruys & Aarts, 2010; Tsai, Kuo, Hung, & Tzeng, 2008; but see Welsh, Higgins, Ray, & Weeks, 2007). As an example, Tsai et al. (2008) asked participants to complete the joint Simon task either with another person performing the respective half of the task from a separate room, or with a computer. The co-actor's performance in their experiment however, was always controlled by a computer program. Under this setting, participants showed a typical joint Simon effect only when the co-actor was believed to be a real person. Although this outcome indicates that co-representation effects are attuned to biological agents (the main topic addressed by Tsai and colleagues), more importantly for the current experiment, their evidence also showed that co-representation effects persist when performing with a (believed) partner in a remote location. Comparable evidence pro task co-representation with believed co-actors was provided by Atmaca et al. (2010) in the context of the joint Flanker task. Moreover, participants in Ruys and Aarts (2010) showed an analogous interpersonal influence (i.e., a joint Simon effect; JSE) when carrying out an auditory joint Simon task with real co-actors performing in adjacent rooms. Taken together these results suggest that the physical presence of the co-actor is not essential for the interpersonal task representation to occur (but see Guagnano, Rusconi, & Umiltà, 2010, for a modification of the JSE where physical proximity became relevant). Instead, it seems that just knowing about the other person's task (even when this person performs from a remote location) may be enough to elicit task co-representation in joint performance settings.

Indeed, more recent research in the joint action field has showed a similar pattern in the context of social offloading (e.g., Tufft et al., 2019). It has been suggested that in some scenarios, we could "offload" irrelevant/distracting information onto others (e.g., a human co-actor), resulting in facilitated performance (i.e., reduced interference when performing a joint task than when completing the task alone). Evidence for this has been obtained employing cross-modal Stroop-like paradigms (i.e., stimulus-stimulus compatibility tasks; Heed, Habets, Sebanz, & Knoblich, 2010; Wahn, Keshava, Sinnett, Kingstone, & König, 2017; see also Knoblich, Butterfill, & Sebanz, 2011), and visual-only picture-word interference (PWI) paradigms (Sellaro, Treccani, & Cubelli, 2018; Tufft et al., 2019). In the solo version of the PWI (Rosinski et al., 1975), participants are presented with picture-word combinations (i.e., a picture with a word written over it per trial). They are asked to name the picture while ignoring the a distractor word. This word could either belong to the same semantic category than the picture (e.g., apple – banana, congruent condition), or not (e.g., banana – castle, incongruent condition). Not surprisingly, participants are slower at naming pictures when the distractor word is semantically unrelated (aka., semantic interference effect; Rosinski, Golinkoff, & Kukish, 1975). Strikingly however, this semantic interference was significantly reduced (or disappeared) when a task partner (Tufft et al., 2019), or an imagined co-actor (Sellaro et al., 2018) responded to the distractor word. This result has been taken to suggest that when provided with a task that allows distributing cognitive responsibilities, participants may "offload" distracting information to a co-actor taking care of it (aka., Social offloading, Tufft et al., 2019). It is beyond the scope of the present Chapter to discuss facilitating (e.g., Heed et al., 2010; Sellaro et al., 2018; Tufft et al., 2019 ; Wahn et al., 2017) vs. interference (e.g., Sebanz et al., 2003) effects in joint performance. Instead, it is worth highlighting that the facilitating interpersonal effect just introduced (i.e., social offloading), was present when performing with a real task partner in one's peripersonal space (Heed et al., 2010; Wahn et al., 2017), that the effect was also present when the partner was in the same room but invisible due to the presence of an opaque divide blocking visual access to her (Tufft et al., 2019), and that it was present when performing the task with an imagined co-actor in a remote location (Sellaro et al., 2018). This suggest that the physical presence/proximity of the co-actor is not critical for this interpersonal effect to occur (Sellaro et al., 2018).

Furthermore, as discussed in previous experiments, it has been proposed that sharing attention towards the same objects/tasks with other individuals could cause a more elaborate processing of the co-attended objects/tasks (shared attention theory; Stheynberg, 2015, 2018). The key evidence supporting Shteynberg's theory was obtained from dyads/groups, where the individuals involved completed shared attention related tasks simultaneously while sitting in different rooms (e.g., Shteynberg, 2010;

Shteynberg & Galinsky, 2011; Shteynberg, Hirsh, Galinsky, & Knight, 2014; Shteynberg et al., 2014), or with believed task partners controlled via Amazon Mechanical Turk (e.g., Shteynberg, Hirsh, Galinsky, & Knight, 2014; Shteynberg et al., 2014). This literature however, has also consistently shown the enhanced cognitive processing effects exclusively when co-attending with in-group members. Considering this, a cautionary note was raised in Experiment 4, and a reminder is included here: the fact that the dual attention effect was already present when participants performed the dual attention task with strangers (e.g., Experiments 1 and 3, described in Chapter 2) may suggest that dual attention and shared attention differ at least in the way they are modulated by social context. Nonetheless, similarly to the task co-representation effects previously described, the "we-mode" elicited by shared attention is also present when the co-attending individuals are located remotely.

The present experiment examined whether the physical closeness to the task partner is critical for the dual attention effect to occur. Specifically, the experiment asked whether the dual attention effect would be replicated (or instead, changed) when participants complete the dual attention task from remote locations (e.g., separate rooms), instead of physically next to each other. As suggested above, answering this question acquires tremendous relevance in a "connected world" (e.g., by mass/social media) like the one we currently inhabit. In addition, the answer to this question would be essential to assess the potential to conduct follow-up research (in relation to the dual attention effect) in contexts where dyadic experimental set-ups are hard to implement, or where studying dyads in close physical proximity is not an option. The later is the case for instance, in fMRI research, which would allow the investigation of the neuro-anatomical correlates of dual attention. Indeed, as will be detailed in the methods section below, the current experiment adopted specific modifications to the original dual attention task (i.e., the task proposed in Exp1), in consideration of the possibility of conducting a future fMRI study (beyond the present PhD project) on dual attention. fMRI hyper-scanning setups have been proposed to record fMRI data from two individuals simultaneously, either by synchronising two MRI scanners (e.g., Montague, 2002), or by testing two participants inside the same scanner (e.g., Lee, 2015; Lee, Dai, & Jones, 2012). However, in the setup at Poole Hospital (which is the setup Bournemouth University had access to by the time of this experiment), only one MRI scanner (able to fit a single participant) is available for research purposes. With this in mind, a likely approach allowing a fMRI investigation of dyads performing the dual attention task would be to have one participant performing the task inside the MRI scanner, while the task partner performs remotely (e.g., from the MRI control room)[5]. Hence, knowing whether the dual attention effect persist when sharing the attended spatial locations with a remotely located partner (e.g., in a separate room) becomes crucial.

In the current experiment, individuals in a dyad performed the dual attention task from separate rooms. Considering the evidence presented above regarding task co-representation in joint action (e.g., Atmaca et al., 2011; Ruys & Aarts, 2010; Tsai et al., 2008), social-offloading (e.g., Heed et al., 2010; Sellaro et al., 2018; Tufft et al., 2019 ; Wahn et al., 2017), and shared attention (e.g., Shteynberg, 2010; Shteynberg & Galinsky, 2011; Shteynberg, Hirsh, Galinsky, & Knight, 2014; Shteynberg et al., 2014), it was expected for the dual attention effect to persist in the new experimental setting. That is, a replication of the dual attention effect was predicted when the co-attending individuals completed the task from remote physical locations.

To examine whether the dual attention effect reported in previous experiments would change when performing with a task partner in a different location, the current study proposed a modified version of the dual attention task (see *Figure 13* and *Table 12*). The first and obvious modification was that the individuals in the dyad performed the task sitting in front of computer monitors placed in separate rooms, instead of sitting side by side next to each other. The task was displayed simultaneously in both monitors and controlled by a computer located in one of the rooms. Further modifications to the original task design were proposed to have a higher number of useful trials in the limited amount of time available inside a MRI scanner (for an actual fMRI experiment). For simplicity, these modifications are summarised in *Table 12*, and further explained below. Three important ones deserve to be highlighted here: First, participants performed a choice response discrimination task on their target stimuli (gratings with two possible orientations), responding to all the target stimulus types (instead of performing a go/nogo task). The change to grating stimuli (instead of shapes/sizes) has the purpose of generalising the dual attention findings to more physically comparable stimuli, which would in turn provide more comparable neural

5 An alternative suggestion would be to manipulate the scanned participant's believes so that she thinks is performing the task with an imaginary (actually non-existing) partner. However, a real task partner performing from a separate location may be preferred in order to keep the social context of the task as close as possible to the original paradigm. Further research, beyond the aims of the current study, could test the role of believes regarding the co-attending partner in relation to the dual attention effect.

responses in future neuroimaging studies. Moreover, the change from a go/no-go task to a response choice task allows extending the understanding of the dual attention results to a different cognitive control situation, and would allow a more efficient data collection in the potential future fMRI settings (i.e., a shorter experiment, and/or more trials to be analysed for the scanned participant for a given scanning time). Second, the number of trials for one of the participants (i.e., the participant to be performing inside the scanner in the future fMRI study) doubled the number of trials for the remaining participant. Third, the trial validity was not the same for both participants. For one participant (the one “inside the scanner”), the trial validity was 75%. This participant was instructed to respond to the targets at any side of the screen. For the remaining participant, the stimuli appeared with equal probability at any side of the screen but responses were performed exclusively to targets appearing at the attended/valid location (i.e., the target validity is 100%). The later represents an alternative way of effectively biasing attention towards a specific spatial location, and is commonly employed in visuospatial sustained attention paradigms (see Eimer, 1996; Hillyard, Vogel, & Luck, 1998 for a similar approach).

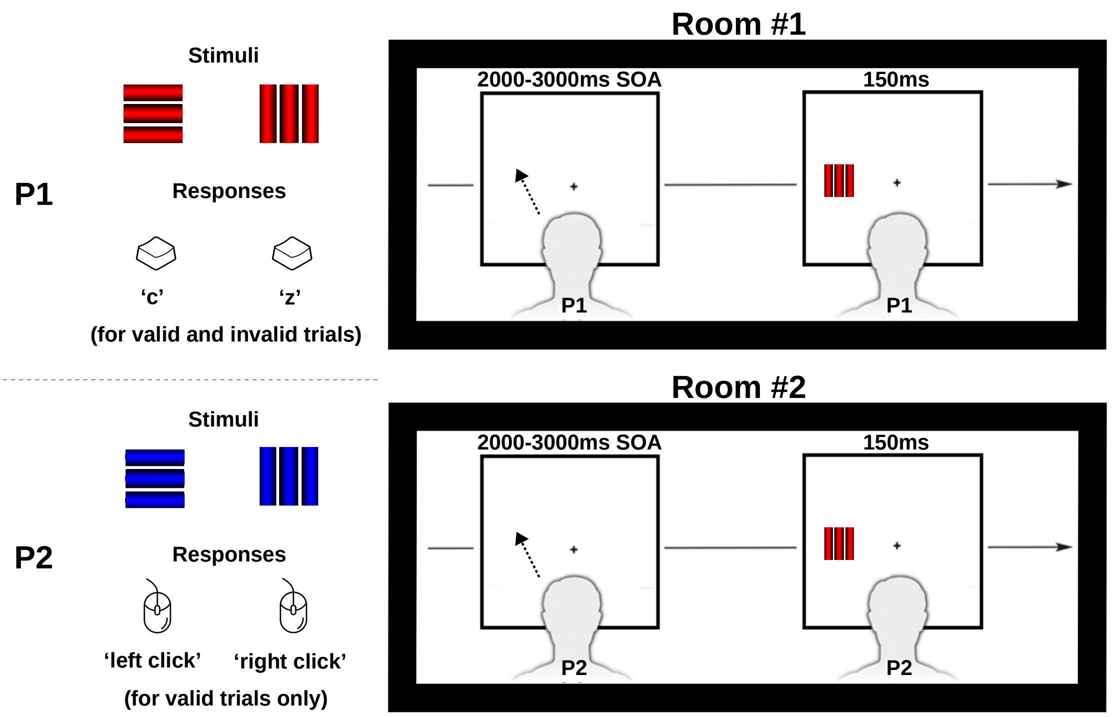


Figure 13. Dual attention task from separate rooms. Participants performed the dual attention task simultaneously from separate locations (different rooms). The monitor and response device in room 2 were connected to the computer in room 1 via a hardware link (i.e., USB and VGA cables).The computer in room 1 executed the experiment and recorded the responses. Participants carried out a sustained attention

task, paying covert attention towards one side of the screen (e.g., left side) for an entire experimental block (this changes across blocks). Across experimental blocks, the attended side of the screen was either simultaneously attended by the participant in the second room (attention shared), or alternatively, the second participant was instructed to focus attention at the opposite location (attention notshared condition). In this version of the task, participants responded to gratings with a target colour (red or blue). These gratings were vertically oriented or horizontally oriented. Participants performed an orientation discrimination task, responding to both orientations with key presses, or mouse clicks. P1 responded to both valid and invalid trials, while P2 responded exclusively to the stimuli appearing at the attended location (valid trials). In this example trial, both participants are paying covert attention towards the left side of the screen (attention shared condition), as indicated by the arrow. A red grating with vertical orientation is displayed at the left side of the screen (the attended location for both participants). P1 should respond to this stimulus pressing ‘z’ on the keyboard. P2 withholds the response. (P1: Participant 1; P2: Participant 2; SOA: Stimulus-onset asynchrony).

3.2.1 Method

3.2.1.1 Participants

Forty-eight participants (24 dyads) took part in this study. However, only the data from the participants responding to both valid and invalid trials were considered (i.e., data from the participants that would be scanned in the actual fMRI experiment).This means that the data from the participants responding only to the valid condition were discarded. Therefore, the data from 24 participants was analysed (20 females; 23 right handed; M_{age}= 20.04, SD_{age}= 2.53). Participants had normal (or corrected to normal) vision and normal colour vision. All of them provided written informed consent to take part in the study, and were given either one (1) course credit or eight pounds (£8) for their participation.

3.2.1.2 Design

The present experiment employed the same 2X2 factorial design than Experiment 1, where Attention (attended vs. unattended location) and Sharing (attention shared vs. notshared) were manipulated within-subjects, and the participant’s reaction times (*RTs*) and accuracies (percentage of correct responses) to the target stimulus were the dependent variables. In the current experiment however, participants performed the task from separate rooms. If the dual attention effect persist in this new experimental settings, this would be reflected in the 2X2 interaction between the above-mentioned factors (i.e., the interaction Attention x Sharing).

Table 12. Comparison between the dual attention task proposed in Experiment 1, and the modified version of the task employed in Experiment 5.

	Original dual attention task (Experiment 1)	**Modified dual attention task (Experiment 5)**
Participant's location	Same room, sitting side by side next to each other	Different rooms
Stimuli	Circles/squares, large/small	Red/blue gratings, vertical/horizontal orientation
Task	Go/no-go, responding to the large target shape (e.g., large circle or large square), holding responses to the small ones Participant 1 & 2 responded to attended and unattended targets (i.e., valid and invalid trials)	Orientation discrimination (vertical/horizontal), responding to both orientations for a target coloured grating Participant 1 responded to attended and unattended targets (i.e., valid and invalid trials) Participant 2 responded **only** to attended targets, ignoring the unattended side (i.e., responded to valid trials only)
Validity	Participant 1: 75% (attended vs. unattended ratio = 3:1) Participant 2: 75% (attended vs. unattended ratio = 3:1) Additional stimuli to balance the overall stimulus distribution (equal number of stimuli for the shared and not shared conditions)	Participant 1: 75% (attended vs. unattended ratio = 3:1) Participant 2: 100% (attended vs. unattended ratio = 1:1) Balanced overall stimulus distribution (equal number of stimuli for the shared and not shared conditions)
Trial ratio (P1:P2)	Equal number of trials for participant 1 and 2	Participant 1's trials number doubled the number of trials for participant 2
Trial duration	150ms (stimulus) + 1350ms ITI	150ms (stimulus), 2-3 seconds jittered SOA

3.2.1.3

3.2.1.4 Materials and procedure

As in the original dual attention paradigm (Experiment 1), participants completed a sustained visual attention task in dyads. In this case, however (see *Figure 13* and *Table 12*), they were performing the task from two separate locations (i.e., two different rooms in the lab). Each participant sat in front of a computer monitor, at a viewing distance of 70 cm (to screen centre). The two monitors (placed in separate rooms) were connected to a single computer, located in one of the rooms. This computer used PsychoPy 1.84 (Peirce et al., 2019; Peirce, 2007) to execute the experiment, control the experimental flow and record the responses. The task was displayed simultaneously in the two monitors by duplicating the screen view. The response devices (i.e., a mouse and a keyboard) were connected to the (same) computer via USB. Visual stimuli were presented against a black background. Participants were instructed to fixate on a white cross displayed in the centre of the screen, while covertly focusing their attention to one side of the visual field for an entire experimental block. Across block the attended side varied from left to right so that the dyad's visual attention across blocks was either focused on the same side (attention shared) or different sides (attention not shared) of the visual field. Unlike the original dual attention task, participants in this experiment responded to coloured (red/blue) gratings (stimulus size: 4.57°x4.57°). These gratings had vertical or horizontal orientation, and were randomly displayed at the left or right side of the screen, one per trial. Each person in the dyad was instructed to respond to gratings with a specific target colour (e.g., one participant responding to the red gratings and the remaining participant responding to the blue ones, counterbalanced). Moreover, instead of the original go/nogo task, in this experiment participants performed an orientation discrimination in a choice response task, responding to each of the possible orientations (horizontal/vertical) using two different button presses. For these responses, one participant was instructed to respond quickly and accurately to the target gratings using the keyboard (keys 'c' and 'z', one per each orientation), while the remaining participant responded using the mouse (left/right clicks). The attention validity also differed from the original task. Here, the attention validity was set differently for each participant (see *Table 12*), and the overall trial distribution was balanced across sharing conditions (i.e., the trials distribution did not differ between attention shared and attention notshared conditions).

As an example of the task performed by each participant, in one experimental session, Participant 1, using the keyboard, had to respond to the red gratings with either vertical or horizontal orientation, using the letters ‘c’ and ‘z’ respectively (counterbalanced). She had to respond to all the red gratings, regardless of the side of the screen they appeared at (i.e., responded to both attended and unattended targets). She was also told that her targets were more likely to appear at one side of the screen, and therefore, she was instructed to focus on this side, to enhance performance in the task (this side could change across blocks). In this same example, Participant 2, using the mouse, had to respond to the blue gratings with vertical/horizontal orientation, pressing a left/right mouse click respectively. This participant however, was instructed to focus on one side of the screen, and to respond only to the gratings appearing at this attended location (i.e., valid trials), ignoring the unattended stimuli (i.e., invalid trials). In this case (remember that the number of trials for Participant 1 doubled the number of trials for Participant 2), 66.66% of all the trials displayed red gratings, and therefore required a response from Participant 1. The remaining 33.33% of all trials displayed blue gratings, but only half of these (50% of the blue gratings, 16.66% of all the trials in the task) required a response from Participant 2 (i.e., only those displayed at the attended side).

A total of 480 trials were completed during the experiment. In half of the trials participants shared the attended locations in the screen (they attended both to the right, or both to the left). In half of the trials attention was not shared (i.e., one attended to the right, and the other to the left, and viceversa). The attending sides order (Participant1-Participant 2: left-left; right-right; left-right; right-left) was counterbalanced. The experiment was divided in eight experimental blocks, varying the instructed focus of attention. These instructions changed every two blocks. Participant took a fixed thirty-second break every 60 trials (i.e., at the end of each block), unless the dyad’s attending sides changed. In this case (i.e., every two blocks), a sixty-second break was allowed. Each participant was informed about the experiment partner’s instructions at the beginning of the experiment. They had to acknowledge reading the instructions regarding the experiment partner’s task. They were reminded of these (and had to acknowledge reading them) before continuing with the task after each break. Stimuli were displayed for 150ms, with a randomised 2-3 seconds jittered stimulus-onset asynchrony (SOA), keeping an average trial duration of 2.5 seconds. Responses were recorded in a 2 seconds-long window after stimulus onset. Responses beyond this window were not registered.

3.2.2 Results

Three participants were excluded from statistical analysis due to accuracies below 75% per design cell. The remaining 21 participants (19 females; 21 right-handed; M_{age}= 20, SD_{age}= 2.51) were analysed. As in the previous experiments, classical ANOVAs, the percentile bootstrap method on 20% trimmed means (Wilcox, 2012), and Bayes factors were employed when analysing both accuracies and reaction times data. These were computed using the R packages '*ez*' (Lawrence, 2016), '*WRS2*' (Wilcox & Schönbrodt, 2014), and '*BayesFactor*' (Morey & Rouder, 2015), respectively.

3.2.2.1 Accuracies

Mean accuracies (see *Table 13*), were submitted to a 2x2 repeated-measures-ANOVA with Attention (attended vs. unattended) and Sharing (shared vs. unshared) as within-subjects factors. However, both the main effects and the interaction were not significant. This was also the case when employing the within-within percentile bootstrap method on 20% trimmed means.

Table 13. Mean accuracies (with SD) for Experiment 5. Mean accuracies are here presented as percentage of correct responses.

Experimental Condition			
Notshared		**Shared**	
Attended	**Unattended**	**Attended**	**Unattended**
93.7(5.52)	93.7(4.91)	93.8(5.17)	92.6(5.09)

3.2.2.2 RTs

Only trials with correct responses were considered (93.6%). Outliers were determined and removed using a threshold of 2.5 times the Median Absolute Deviation (MAD) per design cell. This eliminated 5.9% of the remaining data. Mean RTs (see *Figure 14* and *Table 14*) were submitted to a 2x2 repeated-measures-ANOVA with Attention (attended vs. unattended) and Sharing (shared vs. unshared) as within-subjects factors (see Figure 14). The ANOVA revealed a significant main effect of Attention, $F(1, 20) = 16.21$, $p < .001$, η_G^2 =0.037, due to shorter RTs for the attended stimuli ($M_{attended}$ = 594 *ms*, *95% CI* [566.24, 621.01]) than for the unattended ones ($M_{unattended}$ = 620 *ms*, *95% CI* [586.62, 652.96]). The main effect of Sharing was not significant, *F*(1, 20) = 0.67, *p* = .798, nor the interaction Attention x Sharing, *F*(1, 20) = 0.37, *p* = .550 ($M_{AttEffect,\ shared}$ = 24 *ms*, *95% CI* [9.14, 38.97]; $M_{AttEffect,\ unshared}$ = 28 *ms*, *95% CI* [12.42, 44.14]).

Similarly, the within-within percentile bootstrap on 20% trimmed means yielded a significant main effect of attention, $\hat{\psi}$ = 45 [21.9, 75.1], p = 0, a non significant main effect of Sharing, $\hat{\psi}$ = -9 [-28, 15.6], p =.465, and a non significant interaction Attention x Sharing, $\hat{\psi}$ = 5 [-12.2, 18.7], p =.553. In addition, for this interaction, Bayes factors, BF01 = 3.2 suggested “moderate” support for the model without the interaction, relative to the model with it, given the data.

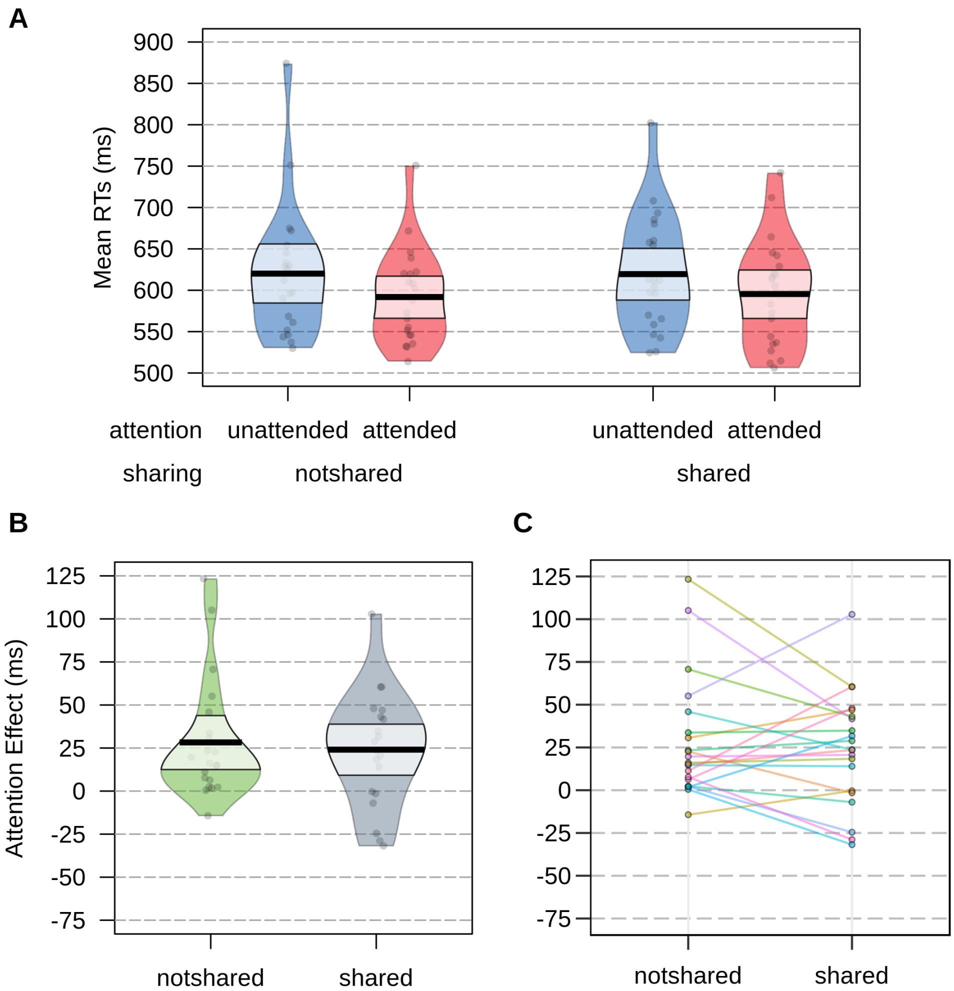


Figure 14. Mean RTs and attention effect Experiment 5. A) Mean RTs as a function of attention (attended, unattended), and sharing (shared, not shared) conditions. The group means for each condition are displayed with 95% confidence intervals (CIs) **B)**

Mean attention effect across sharing (shared, not shared) conditions. The mean attention effect is calculated as the difference between the mean RTs for the unattended condition and the mean RTs for the attended condition (i.e., $M_{AttEffect} = M_{unattended} - M_{attended}$). Means are displayed with 95% confidence intervals (CIs) **C)** Stripchart showing the attention effect for each participant across sharing conditions. Lines were drawn to join paired observations of the 21 participants analysed, 10 showed a positive dual attention effect (i.e., a reduction of the attention effect for the attention shared condition), while 11 showed an effect in the opposite direction (i.e., an enhanced attention effect for the attention shared condition).

Table 14. Mean RTs in ms (with SD) for Experiment 5.

Experimental Condition			
Notshared		**Shared**	
Attended	**Unattended**	**Attended**	**Unattended**
592(57)	620(80)	595(65)	620(70)

3.2.3 Discussion

The present experiment investigated whether the dual attention effect persisted when individuals in a dyad performed the dual attention task from separate rooms. Contrary to the expectation, the obtained evidence favoured the absence of the dual attention effect in this new scenario. As discussed below, this result may suggest that the physical closeness in relation to the task partner is critical for the dual attention effect to occur, but could also be driven by changes in the task parameters implemented in the current design, respect to the original dual attention task. The current results should be followed-up in future research to achieve solid conclusions.

Several research findings have shown interpersonal influences in cognitive processes when performing with remotely present (or even imagined) task partners (e.g., Atmaca et al., 2011; Ruys & Aarts, 2010; Tsai et al., 2008). These evidence comes mostly from experiments employing joint action paradigms (e.g., the joint Simon; Ruys & Aarts, 2010; Tsai et al., 2008, and the joint Flanker tasks; Atmaca et al., 2011), and suggest that just knowing about the other person's task (even when this person performs from a remote location) may be enough to elicit the associated interpersonal influence (i.e., task co-representation in this case) in joint performance settings. Nonetheless, Guagnano, Rusconi, and Umiltà (2010) proposed a modification of the joint Simon task in which the co-actor's physical proximity became critical. In

Guagnano and colleagues' version of the joint Simon task, the co-actors had independent tasks. This was achieved by presenting simultaneously the stimuli for the two participants (in a dyad) in 80% of the trials, strongly reducing the turn-taking aspect of the task. In this setting, a typical JSE was obtained, but disappeared when the co-actor was outside one's peripersonal space (i.e., outside arm-reach). The authors argued that the mechanism behind their JSE may differ from the mechanism behind the traditional JSE obtained when participants perform complementary go/nogo tasks. They suggested physical distance mattered when the task partners were engaged in two independent (instead of complementary/collaborative) tasks, and proposed that in their experiment, the co-actor provided a spatial reference frame for response coding, eliciting the obtained JSE (Guagnano, Rusconi & Umiltà, 2010) .

Perhaps the task partner also provides a spatial reference in the context of the dual attention ask. In the case of dual attention however, instead of a spatial reference for coding one's response, sharing a space with the another individual may be necessary for a joint attention-like spatial triangulation simulation to occur (i.e., in this case, a triangulation between one's covert attention deployment, the other's covert attention deployment, and the jointly attended spatial location). Chapter 2 speculated that merely knowing that the other person shares one's locus of attention could be analogue to obtaining this information (about the other's attentional locus) through gaze following, subsequently activating the series of higher order processes supporting joint attention and facilitating coordination in the social world (e.g., monitoring others, mentalising; see Mundy & Newell, 2007; Tomasello, Carpenter, Call, Behne, & Moll, 2005). It was also argued that the additional resources deployed to a "secondary" task (like mentalising/monitoring) when sharing the attentional locus with another person (respect to the not shared condition) could explain the attention performance drop characterising the dual attention effect. Perhaps this joint attention-like spatial triangulation can only be simulated when the co-attending person provides a spatial reference for it to be feasible (e.g., when present in the same room). Taken together these ideas could account for the finding of a dual attention effect when performing the dual attention task with a partner in the same room, and its absence when the partner is out of reach (in another room) and the spatial reference is unavailable. Additional experiments should test whether this is the case.

Before addressing higher-order processing explanations however, it is important to consider that many task parameters were here modified respect to the original dual attention task introduced in Chapter 2 (this was done in consideration of potential future investigations in fMRI experimental settings; see the methods section above). Thus, it is not clear whether the absence of the dual attention effect in the present experiment, and the differences respect to previous experiments, were due to the changes in the social context of the task (i.e., the physical closeness to the task partner), or due to the changes in the task parameters respect to previous designs. Although I cannot foresee how the current task parameters could possibly account for the absence of the dual attention effect in the current experiment, future research should address the role that the current task parameters (respect to those in the original dual attention task) may play in the present results. This could be achieved for instance, by examining the original dual attention task with participants performing from separate rooms, or by testing the modified version of the task here introduced with participants sat side by side next to each other.

Finally, taken together the findings from Experiment 5 and previous experiments presented in this thesis, may suggest that the dual attention and the shared attention mechanisms differ in the way they are modulated by social context. The evidence supporting the shared attention theory has consistently shown the enhanced cognitive processing effects exclusively when co-attending with in-group members. In contrast, the dual attention effect was already present when participants performed the dual attention task with strangers (e.g., Experiments 1 and 3, described in Chapter 2), and was not modulated by the task partner’s group membership status, at least as induced in Experiment 4. Similarly, the “we-mode” elicited by shared attention is present when the co-attending individuals are located remotely, but the dual attention effect disappeared when performing the dual attention task with a partner in a separate room (Experiment 5). Therefore, the evidence discussed in this thesis in relation to the shared attention theory and the dual attention effect, could be taken to suggest that no single mechanism underlies “co-attending”/”sharing attention” with others in the social world, and that instead, different mechanisms/processes may be called in to action depending on the specific social/cognitive context. As discussed above, these ideas must be considered with caution at the current stage, and should be addressed in future research.

3.3. Chapter summary

The present chapter investigated the role of the social/physical closeness among task partners on the dual attention effect. Experiment 4 manipulated the social closeness aspect by means of a minimal group manipulation. The induced categorising of the task partner as in-group or out-group however, did not modulate the interpersonal influence measured in the dual attention task. The reasons for this lack of modulation by group membership are not well understood, and should be addressed in follow-up experiments to achieve solid conclusions. Nonetheless, the experiment provided an additional replication of the dual attention effect (already obtained in Experiments 1 and 3), adding important confidence regarding its robustness. Experiment 5 examined the role of the partner's physical closeness, indicating (contrary to the expectation) the absence of attention performance changes when sharing vs. notsharing the attentional locus with a physically remote task partner (i.e., in a different room). It was speculated that a joint attention-like spatial triangulation simulation (and related higher order processes like monitoring/mentalising) may be behind the dual attention effect, but would only occur when the task partner is physically available (e.g., in the same room) to provide a spatial reference for this triangulation to be feasible. It is unclear however, whether differences in task parameters respect to the original dual attention task may account for the reported findings. The current chapter left more open questions than answers in relation to the interplay between low-level cognitive processes (i.e., attention performance) and the investigated social factors (i.e., the task partner's social/physical closeness) in the context of dual attention. Additional research should address the open questions, and examine the role of social factors beyond those here investigated.

4

DUAL ATTENTION EFFECT:

SENSORY PROCESSING OR TOP-DOWN CONTROL?

The current PhD thesis aimed at expanding the understanding on interpersonal influences in human attention by asking whether visual attention acts differently (i.e., attention performance is changed) when another person pays attention to the same location one is focused on, in the absence of direct communication or explicit interactions (i.e.., without gaze following/coordination or a speech exchange), just by knowing that the locus of attention is shared, even if this knowledge is irrelevant/trivial for one's task/goals/performance. Experiment 1 addressed this question by proposing the dual attention paradigm (see Chapter 2). In this paradigm, two participants (i.e., a dyad sat side by side next to each other in front of a computer) performed independent sustained attention tasks, responding to target shapes (in a size/shape discrimination task), while attending to one visual hemifield for a whole experimental block. The attended side varied so that the dyad either shared or not the attended spatial hemifield. Taking into account previous findings in relation to the shared attention theory (Shteynberg, 2015, 2018), Experiment 1 hypothesised an enhanced attention performance when the dyad shared the locus of attention in the dual attention task (i.e., attention shared condition), in respect to the condition in which the locus of attention differed (i.e., attention notshared condition). Task performance was measured by the difference in RTs between attended vs. unattended conditions, a typical performance index known as the *attention effect* (Posner, 1980). Therefore, a stronger attention effect was expected for the attention shared scenario. Strikingly however, the results showed the opposite pattern. A reduced attention performance was obtained when the dyad sustained attention towards the same visual hemifield. This was termed *dual attention effect*.

A subsequent experiment (Exp2) investigated the outcome of a single participant performing the exact same task, just without a task partner. The modulation of the attention effect by the attention sharing conditions varied between the solo (Exp2) vs. dyadic (Exp1) version of the task, showing a completely opposite pattern.

The attention effect was enhanced for the “shared” condition in the solo version (i.e., in the condition where most of the large shapes were displayed at the same location), and reduced for the (actual) Shared condition in the two-person task, relative to the “not shared” situation. The effect observed in the solo version was deemed as stimulus driven, attributed to the unbalanced distribution of target shapes in the task (see Chapter 2). Moreover, an additional experiment (EXp3) showed that the dual attention effect remains unaffected under an increased perceptual load, suggesting that the related behavioural attention performance reduction may not be taking place via a sensory-level attentional process, but that instead, the interfering inhibitory process (likely social, and related to the task partner) employs resources from a separate capacity, or is processed at a different stage (Handy & Mangun, 2000; Handy, Soltani, & Mangun, 2001). Considering that higher level processes are less likely to be affected by an increased perceptual load (Handy & Mangun, 2000), the previous result could also suggest that the dual attention effect takes place at a higher level information processing stage in the brain.

Taken together, the above-mentioned experiments point towards the existence of two different processing components in the dual attention task. A stimulus driven component (Exp 2), related to the statistical properties inherent to the behavioural task (i.e., the unbalanced distribution of target shapes across attention sharing conditions), and a social component (Exps 1 & 3), related to the interpersonal influence observed when performing the task in dyads, measured as a reduction in attention performance (i.e., a smaller attention effect) when sharing the attended locations with the task partner (i.e., the dual attention effect). This dual-process account however, cannot be confirmed based exclusively on the aforementioned behavioural data. Additional research is needed to investigate if separate processing modules are indeed behind the dual attention effect. Electroencephalographic (EEG) recordings could be employed for this purpose. Indeed, given its high time resolution relative to other techniques (see Lopes da Silva, 2013, for a review), EEG allows a very precise investigation of the time course of the information processing occurring in the brain, and could be employed to pinpoint the processing stage(s) where the dual attention effect takes place.

4.1. Experiment 6

4.1.1 Introduction

The aim of the current experiment was to investigate the neural correlates characterizing the interpersonal influence over human attention performance observed in the dual attention task. Specifically, the experiment examined the information processing stage(s) influenced by dual attention, and asked whether the dual attention effect (i.e., the socially driven attention performance drop observed when participants shared the locus of attention in the dual attention task), takes place at a sensory-level vs. a cognitive control stage. In order to address this question, EEG was simultaneously recorded from pairs of participants while they performed the dual attention task. Event-related potentials (ERP) analysis were carried out, focusing on the P1 and the N2b ERP components, well known markers of sensory-level attentional processing (Hillyard, Vogel, & Luck, 1998) and cognitive control (Folstein & Van Petten, 2008) respectively. In this line, the ERP component mirroring the behavioural pattern obtained in Exp1 (i.e., showing a reduced attention effect for the attention shared condition) would be considered as a neural correlate potentially driving the dual attention effect.

The current chapter also explores whether the dual attention effect, as reflected in ERPs, relies on the personal task demands. In other words, the effect of an increased perceptual task load is examined, echoing Experiment 3. Although Experiment 3 suggested that the dual attention effect measured in reaction times is not modulated by perceptual load, previous research has shown that perceptual load effects absent in behavioural data may still occur when analysing electrophysiological event-related responses (Handy & Mangun, 2000; Handy et al., 2001). Therefore, it would be valuable to explore if that is the case for the dual attention task. Moreover, and also on an exploratory basis, this chapter evaluates the way in which the task partner’s stimulus set is processed and whether this processing is modulated by the attention sharing conditions.

The first half of the current chapter, introduced in the following paragraphs, presents the ERP analysis in relation to dual attention. In the second half of the chapter, the ERP results are followed-up by examining the role played by neural oscillations in the dual attention effect[6]. Time-frequency analysis (e.g., Cohen, 2018; Herrmann, Rach, Vosskuhl, & Strüber, 2014) were employed for this purpose, investigating particularly the alpha and theta band rhythms, oscillatory indexes of visual attention (Sauseng et al., 2005) and cognitive control (Cavanagh & Frank, 2014) respectively (see the section "Follow-up analysis: Investigating the role of brain oscillations in sensory processing and cognitive control").

4.1.1.1 P1 component

This early positive deflection, typically picking around 100ms, reflects neural activity in the extrastriate cortex when processing physical stimulus properties, and represents sensory level information processing in the brain (Hillyard & Picton, 1987). It has been shown to be modulated by the voluntary orienting of visuo-spatial attention (e.g., Van Vorhis & Hillyard 1977; see Hillyard, Vogel, & Luck, 1998 for a review). In particular, in sustained attention experiments, where participants are asked to fixate the centre of the screen while focusing their attention to one particular location, enhanced P1 are obtained for stimuli appearing at the attended locations compared to the unattended ones (e.g., Luck, Woodman, & Vogel, 2000; Mangun, Hillyard, & Luck, 1993). Larger P1 are also found when focusing on local vs. global features in a Navon task (Han, Fan, Chen, & Zhuo, 1997; Han, Liu, Yund, & Woods, 2000), suggesting that paying attention to hierarchical levels of stimuli affects the early visual processes reflected by P1. In addition, P1 has been shown to be modulated by perceptual load, with an enhancement in P1 amplitudes for perceptually more difficult tasks (e.g., Handy & Mangun, 2000; Handy et al., 2001). This result indicates that the early sensory processes in the brain are also influenced by perceptual load. Moreover, it has been shown that increasing the perceptual load to (foveal) targets in spatial cueing tasks derives in a decreased P1 response to (parafoveally presented) task-irrelevant stimuli, respect to a low-perceptual-load condition (Handy et al., 2001). In line with the load theory (e.g., Lavie, 2005, 2010), this outcome has been taken to suggest that an increased load for target stimuli reduces the residual attentional capacity available to process task-irrelevant information, and that P1 indexes this attentional capacity consumption (Handy et al., 2001).

6 Experiment 6 was designed as an ERP study of the dual attention effect. The additional analysis on neural oscillations were only considered and performed as a follow-up to the ERP findings. The author wanted to reflect this sequence in the Chapter's structure. For this reason, the oscillations related analysis are only introduced in the second half of the Chapter, after presenting the ERP results.

P1 amplitudes can be further modulated by the social context of the task. Studies employing traditional gaze-cueing paradigms reported enhanced P1 event-related responses for valid (i.e., trials were the gaze shift predicted the target location), compared to invalid trials (i.e., trials were the target appeared at the opposite location indicated by the cue) (Schuller & Rossion, 2005; Schuller & Rossion, 2001, 2004; Tipper, Handy, Giesbrecht, & Kingstone, 2008), echoing typical findings in the visuospatial attentional orienting literature (e.g., Van Vorhis & Hillyard 1977; Hillyard, Vogel, & Luck, 1998) . More recently, event-related responses have been examined using more elaborated social manipulations in relation to joint attention (e.g., Böckler & Sebanz, 2012; Caruana, de Lissa, & McArthur, 2015, 2017; Caruana & McArthur, 2019; Wykowska, Wiese, Prosser, & Müller, 2014). For instance, in Wykowska, Wiese, Prosser, and Müller (2014), participants completed a typical gaze-cueing task with a centrally presented face of a humanoid robot. In this task, the robot was either gazing towards the location where a subsequent target would appear (valid trial), or the opposite (invalid trial). Participants were either told that the robot's gaze was controlled by a human or by a computer. Under these conditions, participants ERP responses time-locked to the target onset were examined, revealing a stronger P1 amplitude for valid than invalid trials, but only when the robot's gaze was believed to be controlled by a human. This was interpreted by the author's as potentially suggesting that adopting (or not) an intentional stance towards the robot (i.e., assuming that it has a mind) top-down modulated the attentional control over the early sensory processes measured by P1 (i.e., sensory gain) (Wykowska et al., 2014).

In addition, evidence from joint action settings suggest that co-representing a co-actor's focus of attention may modulate the early attentional processes reflected by P1. As previously introduced in this thesis, Böckler, Knoblich and Sebanz (2012) employed a dyadic version of the Navon task to study task co-representation in attentional settings. As a reminder, in the single person version of the Navon task (Navon, 1977), participants are presented with a large letter (global stimulus feature) formed by many small letters (local stimulus feature), and their task is to discriminate/identify one of the two (i.e., either the local or the global feature of the stimuli). Faster responses are usually performed to the global compared with the local stimulus features. Moreover, regardless of the focus of attention (local or global), responses are typically impaired/slowed down when these features are incongruent (e.g., attending to the global feature when the stimuli is a large letter H formed by small letters Ss), compared to the congruent condition (e.g., attending to the global feature when the stimuli is a large letter H formed by small letters Hs). In the two-persons version of this task proposed by Böckler, Knoblich and Sebanz, participants still respond to the identity of the letters, but they are either focusing on the same (e.g., both people attending to the local stimulus features) or different (e.g., one person attending to the local feature, and the other person focusing on the global feature of the stimulus) aspects of the task. In this dyadic setting, participants were slower at responding when the co-actor had a different focus of attention, suggesting that the different attentional focus employed by (or instructed to) the co-actor interfered with ones own focus when performing the task (Böckler, Knoblich, & Sebanz, 2012). Importantly for the current experiment, in the joint setting proposed by Böckler and colleagues, a significant reduction in P1 amplitudes was found when the co-actor had a different focus of attention (Böckler & Sebanz, 2012b). The authors suggested this could be explained by an increased difficulty in selecting one's focus of attention when the co-actor's one differed.

In the current study, a typical attentional effect in P1 amplitudes would be expected, with a larger P1 for the attended than unattended stimuli. This would replicate previous findings reported in literature (see above). In addition, if the dual attention effect influences the early sensory processing related to the P1 component, a dual attention effect should be obtained in P1. That is, a smaller attention effect when the dyad shares the attentional locus in the task than when the locus of attention differs. Moreover, if an increased perceptual load reduces this interpersonal social influence in the dual attention task, a three-way interaction Attention x Sharing x Load would be expected, with a smaller Attention x Sharing interaction (i.e., a reduced attention effect) for the High vs. Low Load condition.

Alternatively, it could happen that P1 amplitudes show a larger attention effect for the attention shared than for the notshared condition, rather than the attention performance drop characterising dual attention. Two different reasons could drive this result. On the one hand, Experiment 2 already showed this opposite pattern, and argued it could be potentially driven by the statistical properties of the stimuli in the dual attention task. If this stimulus driven effect influences the early sensory processing related to the P1 component, then P1 amplitudes should show the same pattern. In addition, following the findings by Böckler and Sebanz (2012) in the joint Navon task, it could be plausible to expect that sharing the attended locations in the dual attention task would elicit larger P1 and greater attentional effects than when the participants' locus of attention differs.

4.1.1.2 N2b component

The N2b component is a negative deflection peaking around 200-350ms after the stimulus onset, known to be originated in the medial prefrontal cortex (mPFC), particularly in the anterior cingulate cortex (ACC) (Crottaz-Herbette & Menon, 2006; Van Veen & Carter, 2002). As the P1 component, the N2b is modulated by visual attention, with larger N2b amplitudes typically obtained in response to attended than unattended stimuli (e.g., Eimer, 1993; see also Wei, Rushby, & De Blasio, 2019). More importantly however, the N2b component has been considered a marker of cognitive inhibitory control and conflict monitoring (see Folstein & Van Petten, 2007 for a review; see also Vuillier, Bryce, Szücs, & Whitebread, 2016). In this line, this ERP component typically measured at fronto-central sites, is larger when inhibiting prepotent responses is required (i.e. response inhibition; see Folstein & Van Petten, 2008). For instance, the larger N2b are obtained for incongruent than congruent trials in cognitive control tasks (Folstein & Van Petten, 2007; Larson, Clayson, & Clawson, 2014; Van Veen & Carter, 2002), and enhanced N2b have been found for no-go trials in go/nogo tasks (Jodo & Kayama, 1992; Pfefferbaum, Ford, Weller, & Kopell, 1985). This no-go N2 has been further shown to be enhanced when the no-go stimuli share target features, inducing a response that needs to be suppressed (e.g., Azizian, Freitas, Parvaz, & Squires, 2006). Additional evidence has suggested that attention may play an important modulating role on the effect obtained in go/nogo paradigms, with larger anterior N2s for attended stimuli (Eimer, 1993). The effect on the anterior N2 component however, seems to be less clear in paradigms where interference arising from irrelevant/ambiguous information needs to be suppressed (i.e., response conflict paradigms), since different effect-directions have been obtained for the Stroop task and doubts about the real meaning of the anterior N2 have been raised for the Flanker task (Vuillier, Bryce, Szücs, & Whitebread, 2016).

In the current experiment, an attention effect in N2b amplitudes is expected. That is, greater (more negative) amplitudes for those stimuli that are attended vs. those unattended. Moreover, If cognitive control is behind the dual attention effect, a modulation in the attention effect by the attention Sharing is expected in the N2b amplitudes, echoing the behavioural findings in Experiments 1 and 3. That is, a reduced attention effect when the dyad sustains attention towards the same spatial location, than when their locus of attention differs. In addition, as introduced above, the current study also explores whether the ERP correlates of dual attention are modulated by perceptual load. In this line, if the N2b data showed a dual attention effect, a modulation by task load would be of interest. A three-way interaction Attention x Sharing x Load would be expected if task load reduces the social influence under dual attention. In this case, a stronger interaction Attention x Sharing interaction (i.e., a large attention effect) would be expected for the Low Task Load condition then for the High Load scenario.

Finally, the P1 and N2b amplitudes were also evaluated time-locked to the task partner's stimuli, but this was done in a purely exploratory fashion.

4.1.2 Method

4.1.2.1 Participants

Thirty-eight volunteers (19 dyads) participated in Experiment 6 (22 females; 34 right handed; M_{age}= 23.18, SD_{age}= 4.29). All of them reported normal or corrected-to-normal vision and no known neurological impairment. They provided written informed consent to take part in the study, and were given either course credits or a monetary payment (£8/hour) for their participation.

4.1.2.2 Design

The current experiment employed a 2x2x2 factorial design, where Attention (attended vs. unattended location), Sharing (attention shared vs. notshared), and Load (low vs. high perceptual load) were manipulated within-subjects. The dependent variables were the P1 and N2b evoked amplitudes to one's non-target stimulus (see below). The evoked responses to the co-actor's non-target stimulus were also considered in a exploratory fashion.

4.1.2.3 Materials and procedure

The current experiment employed the same stimuli as Experiments 1 and 3 (i.e., circles/squares, large/small) (see *Figure 15*), presented in two consecutive experimental sessions varying the task load (i.e., easy vs. hard size discrimination, counterbalanced; see “Procedure” section below). The size of the large stimuli was always set to 4.57° x 4.57°. The size of the small stimuli on the other hand, was 2.38° x 2.38° for the easy size discrimination task (as in Exp1), and 3.97° x 3.97° for the difficult task (as in Exp3). Visual stimuli were presented in white against a black background. Stimuli were presented on a CRT monitor, at a screen resolution of 1920 × 1080 pixels and a refresh rate of 85Hz. E-prime 2.0 was used to program the experiment, control the experimental flow and record the responses. The responses were made using a standard mouse and keyboard.

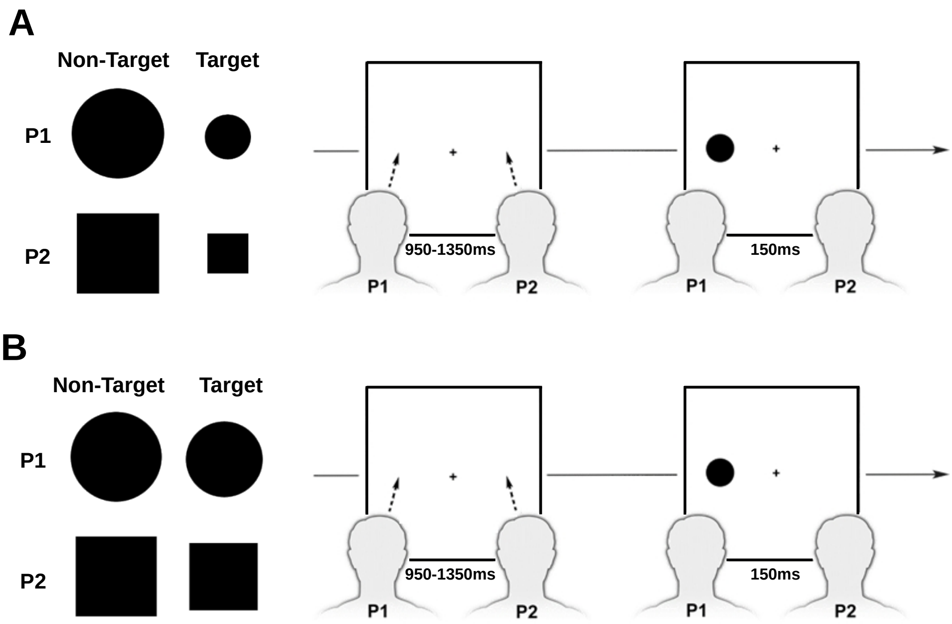


Figure 15. Experiment 6. The task for Experiment 6 combined the task sets and procedures employed in Experiments 1 and 3. During each trial, participants fixated a white cross displayed in the centre of the computer’s screen, while focusing their attention to one side of the visual field. Either large or small discs or squares were randomly displayed at the left or right side of the screen, one per trial. Each person in the dyad was assigned a stimulus shape (e.g. squares, counterbalanced) and had to quickly respond exclusively to the small version of the stimuli with their assigned shape (e.g. respond only to small squares), appearing in the attended side of the screen. Manual responses had to be withheld to non-targets. 50% of the target stimuli appeared on the attended side of the screen (valid trials), and 50% of them appeared at the opposite location (invalid trials). They focused attention on one side of the screen (containing 50% of the targets) in each block, and responded only to the targets appearing at the attended location (2:1 non-target vs. target ratio). The perceptual load of the task varied in two consecutive experimental sessions (counterbalanced). **A)** Employed the same perceptual load as in Experiment 1. **B)** Employed the same perceptual load as in Experiment 3.

The task sets and procedures employed in Experiments 1 and 3 (see *Figure 15*) were here combined (with some modifications, see below). Participants performed both an easy (aka., low task load, as in Exp1) and a difficult (aka., high task load, as in Exp3) version of the size discrimination task proposed throughout this thesis, with the order counterbalanced). Participants completed the sustained visual attention task while sitting side by side next to each other in front of a computer monitor while EEG was simultaneously recorded from the two heads. As in previous experiments, the instructed focus of attention varied across blocks (i.e. participants deployed attention to the left or right visual field), with the dyad either focusing on the same side (attention shared), or on different sides (attention NotShared) of the visual field. Participants were constantly reminded (before starting each block of trials) to try to avoid eye blinks and movements during the stimulus presentation, and to keep looking at the central fixation cross throughout the experiment. As in the previous experiments, the viewing distance was set to 70cm.

The trial procedure mirrors the one used in Experiments 1 and 3, with some exceptions (see *Figure 15*). First, 50% (instead of 75%) of the target shapes appeared at the attended side of the screen, and participants responded only to valid trials (i.e., responded only to targets at the attended side). In the behavioural experiments described in the previous chapters, a 75% trial validity was employed to encourage sustained attention to the attended side (i.e., the side of the screen instructed to be attended). In the current experiment, sustained attention is encouraged by instructing participants to respond exclusively to the attended side (see Eimer, 1996; Hillyard, Vogel, & Luck, 1998 for a similar approach). Second, the small stimuli (with the assigned shape) were set as targets, instead of the large ones (e.g., Participant 1 responded to the small squares, Participant 2 responded to the small circles; counterbalanced across participants), and only the evoked responses to non-target stimuli were considered for analysis (e.g., evoked responses to the large squares for Participant 1, and to the large circles for Participant 2). These later changes were aimed at maximising the evoked response to be analysed (given that stronger ERPs are typically elicited by larger stimuli; Celsia, 1993), and to avoid the data contamination induced by manual responses to target shapes (Luck, 2014). In addition, to increase the number of trials available for analysis, the non-target stimuli displayed doubled the amount of target stimuli (2:1 non-target vs. target ratio). Stimuli were displayed for 150ms, with a jittered inter-trial-interval (ITI) between 900ms and 1300ms. Short breaks were allowed every 100 trials. A total of 2400 trials were completed during the experiment, 1200 per experimental session (low vs. high perceptual load). From these 1200 trials per session, participants responded to 200 trials (i.e., to the small stimuli with the target shape, displayed at the attended side; 100 per each participant), while EEG activity for 800 trials were considered for analysis (i.e., EEG responses to the large stimuli with the target shape, displayed either at the attended or unattended side; 400 per each participant). The remaining 200 trials corresponded to stimuli that were not responded to by the participants, nor considered for EEG analysis (i.e., the small stimuli with the target shape, displayed at the unattended side; 100 per each participant). As in previous experiments, responses were made with a left-mouse-click for the participant sat on the right, and with a “space bar” key press for the person sat on the left. The responding hand was counterbalanced across subjects. Responses were recorded in a response window of 900*ms* after stimulus onset.

4.1.2.4 Behavioural data analysis

As introduced above, the experimental design here employed contains two important differences respect to the behavioural dual attention experiments presented in the previous Chapters. Here, a 50% target validity (instead of 75%) was employed, and the participants responded exclusively to targets appearing at the attended side of the screen (while in the previous experiments responses where made to both attended and unattended locations). In addition, to avoid contamination derived from manual responses, only electrophysiological responses to non-target stimuli (which doubled the number of target ones) were considered for the EEG analysis. These are typical choices in the EEG literature (Cohen, 2014a; Luck, 2014), however, they have important implications in terms of the behavioural data available for analysis, and limits the study of potential links between EEG and behaviour. Particularly, since participants responded only to targets at attended locations, no data were available for unattended locations, and therefore, no clear measure of behavioural attentional performance could be derived. That is, no attention effect was available in RTs. In addition, since RTs to attended targets were performed and recorded, and only EEG to non-target stimuli were analysed, these two datasets could not be correlated to investigate their relationship.

Although a clear measure of attention performance was not possible (i.e., no attention effect), here, for completeness, the available behavioural data were examined (i.e., the responses to target stimuli displayed at attended locations). The full sample size was considered for statistical analyses (i.e., 38 participants). Participants showed accuracies ranging from 80% to 100%. All the analyses were performed using R (version ‘1.1.456’) and RStudio (RStudio Team, 2016). As in the previous Chapters, the analyses employed classic ANOVAs, the percentile bootstrap method on 20% trimmed means (Wilcox, 2012), and Bayes factors. These were computed using the R packages ‘*ez’* (Lawrence, 2016), ‘*WRS2’* (Wilcox & Schönbrodt, 2014), and ‘*BayesFactor’* (Morey & Rouder, 2015), respectively.

4.1.2.5 Electrophysiological recordings

The EEG activity was recorded with BrainAmp DC amplifiers (Brain Products GmbH, Munich, Germany) 30 Ag/AgCl electrodes (Fp1, Fp2, Fz, F3, F4, F7, F8, FCz, Cz, C3, C4, T7, T8, CPz, CP3, CP4, Pz, P3, P4, P7, P8, POz, PO3, PO4, PO7, PO8, PO9, PO10, O1, O2) placed on scalp surface following the extended 10-20 system (Chatrian, Lettich, & Nelson, 1985). The EEG signal was acquired with a sampling rate of 1000Hz and a resolution of 0.1µV. The system’s online filtering parameters were set up to 0.01Hz (low-frequency cutoff) and 250Hz (high-frequency cutoff). Impedances for each channel were kept below 20kΩ before testing. To obtain the dual-EEG recordings, a split ground channel was used. Both participants in a dyad shared this split ground electrode, which was positioned on the AFz location for each of them. Additional electrodes were placed on each participant’s left (M1) and right (M2) mastoids. The left mastoid electrode of the participant sitting on the left was used as the physical reference of the system. For each participant, the individual recordings were re-referenced off-line to the average of his/her own mastoid electrodes (M1 and M2).

4.1.2.6 Event-related potentials (ERP) data analysis

The ERP data were analysed in MATLAB 8.3 (MathWorks Inc. Natick, MA) using the EEGLAB toolbox (Delorme & Makeig, 2004), the ERPLAB toolbox (Lopez-Calderon & Luck, 2014), the Fieldtrip toolbox (Oostenveld, Fries, Maris, & Schoffelen, 2011), the LIMO toolbox (Pernet, Chauveau, Gaspar, & Rousselet, 2011), and customized scripts. The data were low pass filtered at 40 Hz and high pass filtered at 0.1 Hz, using Butterworth filters with order 4 (24dB/oct). Prior to applying the high pass filter, the DC offset was removed from the signals. Only trials containing non-target stimuli were considered for further analysis. Trials with responses to non-targets were excluded. The remaining data were segmented into epochs [-100ms, 600ms] time-locked to the stimulus onsets. The period of 100ms before the stimulus onset was used to calculate the baseline and the epochs were baseline corrected. Both threshold (±60 μV) and moving window (peak to peak amplitude 100μV, window size 200ms, window step 50ms) methods were applied for artefact detection. Epochs marked as artifactual were excluded from further analysis. Participants with more than 40% of the epochs rejected were removed (8 participants in total). The remaining epochs were averaged separately for each condition. Grand average waveforms were computed from the individual averages from the remaining 30 participants.

Statistical analyses were performed on the P1 and N2b components. For both ERP components the electrode sites and time windows of interest were determined using collapsed localisers (Luck, 2014; Luck & Gaspelin, 2017). That is, for the contrast of interest (i.e., the attention effect), the average of the grand average waveforms (aka. grand-grand average waveform; Luck & Gaspelin, 2017) was computed across the conditions to be analysed (i.e., Sharing: shared, notshared; Load: low, high) (see *Figure 16*). From these grand-grand average attention effect waveforms, for each component, the electrodes and time ranges displaying the largest attention effect were chosen as the analysis parameters to examine the non-collapsed data. In this way, the P1 component was subsequently quantified by measuring the average mean EEG amplitude at parieto-occipital sites (PO7/8, PO9/10) contralateral to the stimulus location, in the time window [110-130*ms*]. For the N2b component the mean amplitude at fronto-central sites (FCz, Cz) in the time window [240-260ms] was evaluated. The grand-averaged waveforms are presented in *Figure 17* (P1) and *Figure 18* (N2b). The statistical analyses were performed using R (version '1.1.456') and RStudio (RStudio Team, 2016). Mean ERP amplitudes data were analysed employing classic ANOVAs, the percentile bootstrap method on 20% trimmed means (Wilcox, 2012), and Bayes factors. These were computed using the R packages '*ez'* (Lawrence, 2016), '*WRS2'* (Wilcox & Schönbrodt, 2014), and '*BayesFactor'* (Morey & Rouder, 2015), respectively.

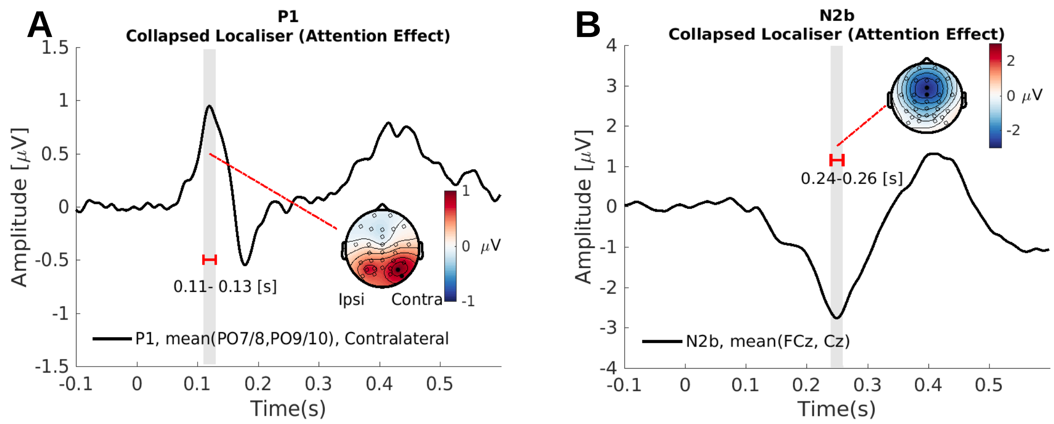


Figure 16. Collapsed localisers for ERPs. Collapsed localisers were employed to determine the electrode sites and time-windows of interest for the P1 and N2b components. **A) P1 component**. Contralateral parieto-occipital sites (PO7/8, PO9/10) and the time window [110-130*ms*] were considered for the subsequent analysis on the non-collapsed data. **B) N2b component**. Fronto-central sites (FCz, Cz) in the time window [240-260ms] were considered for statistical analysis.

4.1.3 Results (Behaviour)

4.1.3.1 Accuracies

Mean accuracies (to target stimuli at attended locations) (see *Table 15*), were submitted to a 2x2 repeated-measures analysis with Sharing (attention shared vs. notshared) and Load (low vs. high perceptual load) as within-subjects factors. The ANOVA revealed a significant main effect of Sharing $F(1, 37) = 4.28$, $p = .046$, η^2_G =0.014, but this result was not supported by the robust test (i.e., the percentile bootstrap on 20% trimmed means), $\hat{\psi}$ = 1.42 [-0.21, 2.92], $p = .091$. The main effect of Load was significant, $F(1, 37) = 25.64$, $p < .001$, η^2_G =0.206; $\hat{\psi}$ = -6.54 [-8.42, -4.67], p = 0. Participants showed lower accuracies when responding to the high perceptual load condition ($M_{highload}$ = 94.03 %, *95% CI* [92.67, 95.38]), than to the low perceptual load scenario ($M_{lowload}$ = 97.63 *ms*, *95% CI* [97, 98.26]). The interaction Sharing x Load was not significant for the ANOVA test, $F(1, 37) = 3.00$, $p = .091$, but the opposite result was obtained with the robust method, $\hat{\psi}$ = -1.42 [-2.38, -0.17], $p = .033$. The effect of Sharing was subsequently examined separately for each Load condition. In the low perceptual load setting, participants performance dropped when sharing attention with the task partner, compared to the attention notshared condition, $F(1, 37) = 8.42$, p

= .006, η^2_G =0.076; $\hat{\psi}$ = 0.96 [0.33, 1.67], *p* = .002. No statistical difference across Sharing conditions was obtained for the high perceptual load condition, *F*(1, 37) = 0.46, *p* = .502; $\hat{\psi}$ = 0.21 [-0.83, 1.29], *p* = .691.

Table 15. Mean accuracies (with SD) for Experiment 6. The accuracies here presented indicate the percentage of correct responses to target stimuli displayed at attended locations.

Experimental Condition			
Low perceptual load		**High perceptual load**	
Shared	**Notshared**	**Shared**	**Notshared**
96.95(2.88)	98.32(1.83)	93.84(4.51)	94.21(4.41)

4.1.3.2 RTs

From the go-trials, only trials with correct responses were analysed (92.6%). Outliers were determined and removed using the 2.5-Median Absolute Deviation (MAD) method. This eliminated 4.9% of the remaining data.

Mean RTs (to target stimuli at attended locations), were submitted to a 2x2 repeated-measures analysis with Sharing (attention shared vs. notshared) and Load (low vs. high perceptual load) as within-subjects factors (see *Table 16*). The ANOVA revealed a significant main effect of Load, *F*(1, 37) = 17.48, *p* < .001, η^2_G =0.097, supported by the outcome of the robust test (i.e., the percentile bootstrap on 20% trimmed means), $\hat{\psi}$ = 51.39 [26.3, 81.05], *p* < .001. RTs were faster for the low perceptual load condition ($M_{lowload}$ = 473 *ms*, *95% CI* [460, 487]), than for the high load scenario ($M_{highload}$ = 500 *ms*, *95% CI* [488, 513]). The main effect of Sharing was not significant, *F*(1, 37) = 0.04, *p* = .836; $\hat{\psi}$ = -2.12 [-11.39, 7.34], *p* = .648, nor the interaction Sharing x Load, *F*(1, 37) = 4.28, *p* = .046, η^2_G =0.014; $\hat{\psi}$ = 7.25 [-8.836, 22.56], *p* = .372. Indeed, for this interaction, Bayes factors, BF01 = 3.245 suggested “moderate” support for the model without the interaction, relative to the model with it, given the data. Given that the main interest here was on the RTs for the low perceptual load condition, I run additional analysis to examine the effect of Sharing for each perceptual load condition separately. RTs were not statistically different across Sharing conditions for the low perceptual load condition, $F(1, 37) = 0.99$, $p = .326$; $\hat{\psi} = -4.14$ [-12.82, 5.05], $p = .372$, nor for the high perceptual load setting $F(1, 37) = 0.70$, $p = .408$; $\hat{\psi} = 5.56$ [-3.36, 13.62], $p = .213$.

Table 16. Mean RTs in *ms* (with SD) for Experiment 6. Mean RTs to target stimuli displayed at attended locations are here presented.

Experimental Condition			
Low perceptual load		**High perceptual load**	
Shared	**Notshared**	**Shared**	**Notshared**
475(43)	471(44)	499(42)	502(38)

4.1.4 Results (ERPs)

Statistical analysis (i.e., classic ANOVAs, percentile bootstrap on 20% trimmed means, and Bayes factors) were performed on each ERP component (P1, N2b). The main interest here was on the event-related responses time locked to one's own stimuli for the low perceptual load condition. The responses to the high load condition, and the responses time locked to the co-actor's stimuli were also analysed. The latter however, were deemed as exploratory.

4.1.4.1 P1 component

P1 mean amplitudes data in the time window of interest [110-130*ms*] were submitted to separate 3-way analysis (rmANOVA, robust method, and Bayes Factors) for each stimulus type (own vs. coactor's) (see *Table 17*). The 3-way interactions Attention (attended vs. unattended) x Sharing (attention shared vs. notshared) x Load (low vs. high perceptual load) were not significant for both the P1 responses to the own and to the coactor's stimuli, and in both cases, Bayes Factors ($BF10 = 0.268$, and $BF10 = 0.294$, respectively) suggested "moderate" support for the model without the interaction, given the data. Given that the main interest here was on the event-related responses time locked to one's own stimuli for the low perceptual load condition, and considering that a clear a-priori hypothesis was made for the interaction between attention and sharing conditions (i.e., the dual attention effect) under low perceptual load, a separate 2-way analysis was run for this particular case (see also Perugini, Gallucci, & Costantini, 2018; Wahlsten, 1991; for arguments suggesting that a higher sample size may be needed to detect interaction effects in factorial designs). For clarity, separate analysis for the P1 responses to the own stimuli in high load, the partner's stimuli in low load, and the partner's stimuli in high load, were also performed. The results are presented below, and should be interpreted with caution.

Table 17. Mean P1 amplitudes in μV (with SD), at contralateral sites (PO7/8, PO9/10), in the time window [110-130ms].

		Experimental Condition			
		Notshared		**Shared**	
Stimuli	**Perceptual load**	**Attended**	**Unattended**	**Attended**	**Unattended**
Own	**Low**	1.71(1.43)	1.42(1.50)	2.12(1.71)	1.34(1.40)
	High	2.10(1.94)	1.33(1.65)	2.02(1.73)	0.94(1.67)
Co-actor's	**Low**	2.09(1.85)	1.31(1.37)	2.29(1.80)	1.30(1.70)
	High	2.02(1.80)	1.53(1.27)	1.81(1.56)	1.06(1.52)

4.1.4.1.1 P1 component: own stimuli, low task load

The data regarding the P1 component for own stimuli and a low task load are summarised in *Figure 17a*. Mean ERP amplitudes data were submitted to a 2x2 repeated-measures-ANOVA with Attention (Attended vs. Unattended) and Sharing (Shared vs. Notshared) as within-subjects factors (see *Figure 17a*). The ANOVA revealed a significant main effect of Attention, F(1, 29) = 9.62, p = .004, η^2_G =0.031, due to a typical attention effect in P1 amplitudes. That is, larger P1 amplitudes were obtained for the Attended stimuli ($M_{attended}$ = 1.91 μV, 95% CI [1.36, 2.47]) than for the Unattended ones ($M_{unattended}$ = 1.38 μV, 95% CI [0.87, 1.89]). More importantly, the attention effect varied across sharing conditions, as indicated by the significant interaction Attention x Sharing, F(1, 29) = 4.70, p = .039, η^2_G =0.007. The attention effect was stronger when attention was shared by the dyad ($M_{AttEffect,\ Shared}$ = 0.78 μV, 95% CI [0.37, 1.2]), than when it was not shared ($M_{AttEffect,\ Notshared}$ = 0.29 μV, 95% CI [-0.15, 0.72]). The main effect of Sharing was not significant.

The percentile bootstrap method on 20% trimmed means showed a significant main effect of Attention, $\hat{\psi}$ = 0.99 [0.30, 1.67], p = .003, a non-significant main effect of Sharing, $\hat{\psi}$ = -0.19 [-0.77, 0.37], p =.516, and a non-significant interaction Attention x Sharing, $\hat{\psi}$ = -0.46 [-0.91, 0.07], p =.094. To address the disparity between classic ANOVAs and the bootstrap method in relation to this 2-way interaction, the attention effect was computed (to directly examine the contrast of interest) and compared across attention sharing conditions by means of a Yuen's test for dependent trimmed means (20% trimming). This yielded a significant difference, M_{diff} = 0.63 [0.16, 0.79], Y_t (17) = 2.54, p= 0.021. For this interaction, Bayes factors (BF10 = 0.868) remained insensitive.

Post-hoc simple main effects analysis examined the effect of Sharing separately for the each of the Attention conditions. Both classic (ANOVA) and robust statistics (percentile bootstrap on 20% trimmed means) yielded a non-significant difference between the P1 amplitudes to attended locations across Sharing conditions, $F(1, 29)$ = 4.10 , p = .052; $\hat{\psi}$ = -0.37 [-0.78, 0.06], p = .093. Similarly, P1 amplitudes to unattended locations were not statistically different across Sharing conditions, $F(1, 29)$ = 0.23 , p = .634; $\hat{\psi}$ = 0.13 [-0.21, 0.45], p = .480.

4.1.4.1.2 P1 component: own stimuli, high task load

The data regarding the P1 component for own stimuli and a high task load are summarised in *Figure 17b*. The 2x2 ANOVA showed a significant main effect of Attention, F(1, 29) = 19.83, p = 1.16e-4, η_G^2 =0.067, due to larger P1 amplitudes evoked by the Attended stimuli ($M_{attended}$ = 2.06 μV, 95% CI [1.40, 2.72]) than by the Unattended ones ($M_{unattended}$ = 1.13 μV, 95% CI [0.54, 1.73]). The main effect of Sharing was not significant, F(1, 29) = 3.01, p = .093, nor the interaction Attention x Sharing, F(1, 29) = 1.64, p = .211.

The outcome of the robust method mirrored the ANOVA results. The percentile bootstrap on 20% trimmed means yielded a significant main effect of Attention, $\hat{\psi}$ = 1.78 [1.07, 2.59], p = 0, a non-significant main effect of Sharing, $\hat{\psi}$ = 0.56 [-0.04, 1.03], p =.070, and a non-significant interaction Attention x Sharing, $\hat{\psi}$ = -0.35 [-0.82, 0.17], p =.186. Bayes factors for this interaction (*BF10* = 0.287) suggested "moderate" support for the model without the interaction, given the data.

4.1.4.1.3 P1 component: co-actor's stimuli, low task load

The data regarding the P1 component for the co-actor's stimuli and a low task load are summarised in *Figure 17c*. The ANOVA yielded a significant main effect of

Attention, F(1, 29) = 14.58, p = 6.54e-4, η_G^2 =0.067, due to larger P1 amplitudes for the Attended stimuli ($M_{attended}$ = 2.19 μV, 95% CI [1.55, 2.83]) than for the Unattended ones ($M_{unattended}$ = 1.31 μV, 95% CI [0.77, 1.84]). The main effect of Sharing was not significant (F(1, 29) = 0.36, p = .555, η_G^2 =0.001), nor the interaction Attention x Sharing (F(1, 29) = 0.48, p = .492, η_G^2 =0.001).

The results after computing the percentile bootstrap on 20% trimmed means pointed in the same direction. This method yielded a significant main effect of Attention, $\hat{\psi}$ = 1.32 [0.51, 2.40], *p* = 0, a non-significant main effect of Sharing, $\hat{\psi}$ = -0.21 [-1.00, 0.54], *p* =.609, and a non-significant interaction Attention x Sharing, $\hat{\psi}$ = -0.25 [-0.89, 0.40], *p* =.493. Bayes factors for this interaction (*BF10* = 0.271) suggested “moderate” support for the model without the interaction, given the data

4.1.4.1.4 P1 component: co-actor’s stimuli, high task load

The data regarding the P1 component for the co-actor’s stimuli and a high task load are summarised in *Figure 17d*. The ANOVA showed a significant main effect of Attention, F(1, 29) = 8.65, p = .006, η_G^2 =0.039, due to a typical attention effect in the P1 amplitudes, with stronger P1 responses for the Attended stimuli ($M_{attended}$ = 1.91 μV, 95% CI [1.32, 2.50]) than for the Unattended ones ($M_{unattended}$ = 1.30 μV, 95% CI [0.81, 1.79]). The main effect of Sharing was also significant, F(1, 29) = 5.94, p = .021, η_G^2 =0.012, with larger P1 responses evoked by the NotShared stimuli ($M_{attended}$ = 1.78 μV, 95% CI [1.25, 2.30]) than by the Shared ones ($M_{unattended}$ = 1.43 μV, 95% CI [0.93, 1.94]). The interaction Attention x Sharing was not significant, F(1, 29) = 0.85, p = .363, η_G^2 =0.002.

The percentile bootstrap on 20% trimmed means mirrored the ANOVA results. It yielded a significant main effect of Attention, $\hat{\psi}$ = 1.39 [0.41, 2.22], *p* = .006, a significant main effect of Sharing, $\hat{\psi}$ = 0.60 [0.03, 1.23], *p* =.034, and a non-significant interaction Attention x Sharing, $\hat{\psi}$ = -0.28 [-0.86, 0.34], *p* =.383. Bayes factors for this interaction (*BF10* = 0.283) suggested “moderate” support for the model without the interaction, given the data

P1 component, own stimuli, low task load

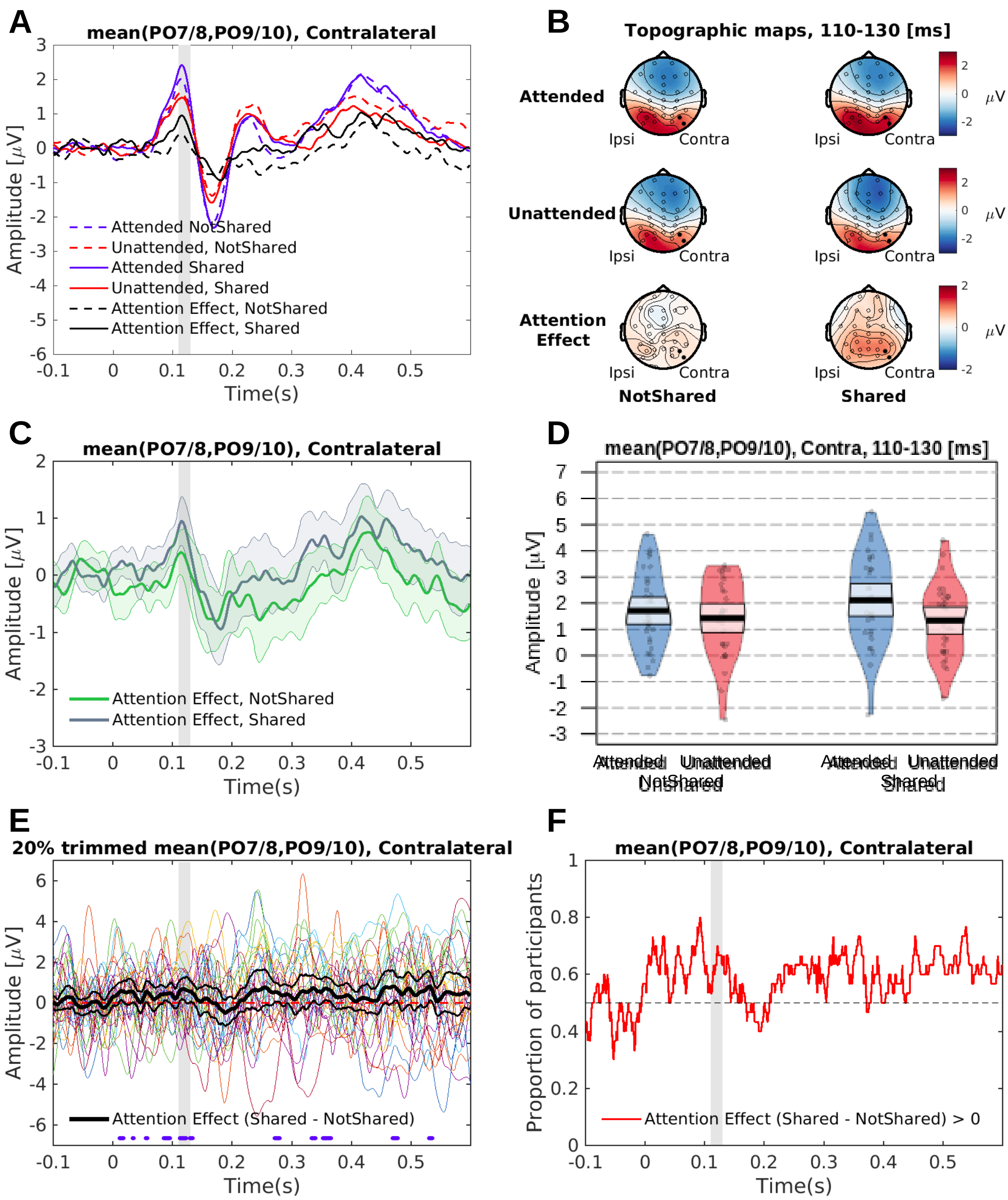


Figure 17a. P1 component for own stimuli and a low task load. A) Grand averaged ERP waveforms. The time window of interest [110-130*ms*] is displayed in grey. **B)** Average topographic maps in the time window [110-130*ms*]. For each topographic map, the right/left hemisphere show the mean amplitude for sites contralateral/ipsilateral to the stimulus location. The dark dots represent the plotted channel locations. **C)** Attention effect across attention sharing conditions. The shaded areas surrounding the waveforms represent 95% CIs. **D)** Pirateplot showing the mean

ERP amplitudes for the time window of interest. The gray boxes surrounding the mean values represent 95% CIs. **E)** 20% trimmed mean difference between the attention effect for the attention Shared and Notshared conditions. This difference is displayed with 95% CIs around the trimmed mean. The coloured waveforms show the difference (i.e., attention effect Shared minus Notshared) for each single participant. The dashed red line represents the zero [*μV*] value. The blue dots at the bottom of the plot (below the plot legend) show the time points where a significant difference (between the attention effect for the Shared vs. Notshared conditions) was obtained using yuen's tests (for dependent groups) on 20% trimmed means (at α=0.05). These values are uncorrected for multiple comparisons. The yuen's tests were computed using the function "*limo_yuend_ttest*", part of the LIMO toolbox (Pernet, Chauveau, Gaspar, & Rousselet, 2011). **F)** Proportion of participants (from 0 to 1, for every time point) showing a stronger attention effect for the attention Shared condition, compared to the Notshared scenario. The plots C, E, and F were created using a modified version of the code available at: https://github.com/GRousselet/blog/tree/master/erp_differences

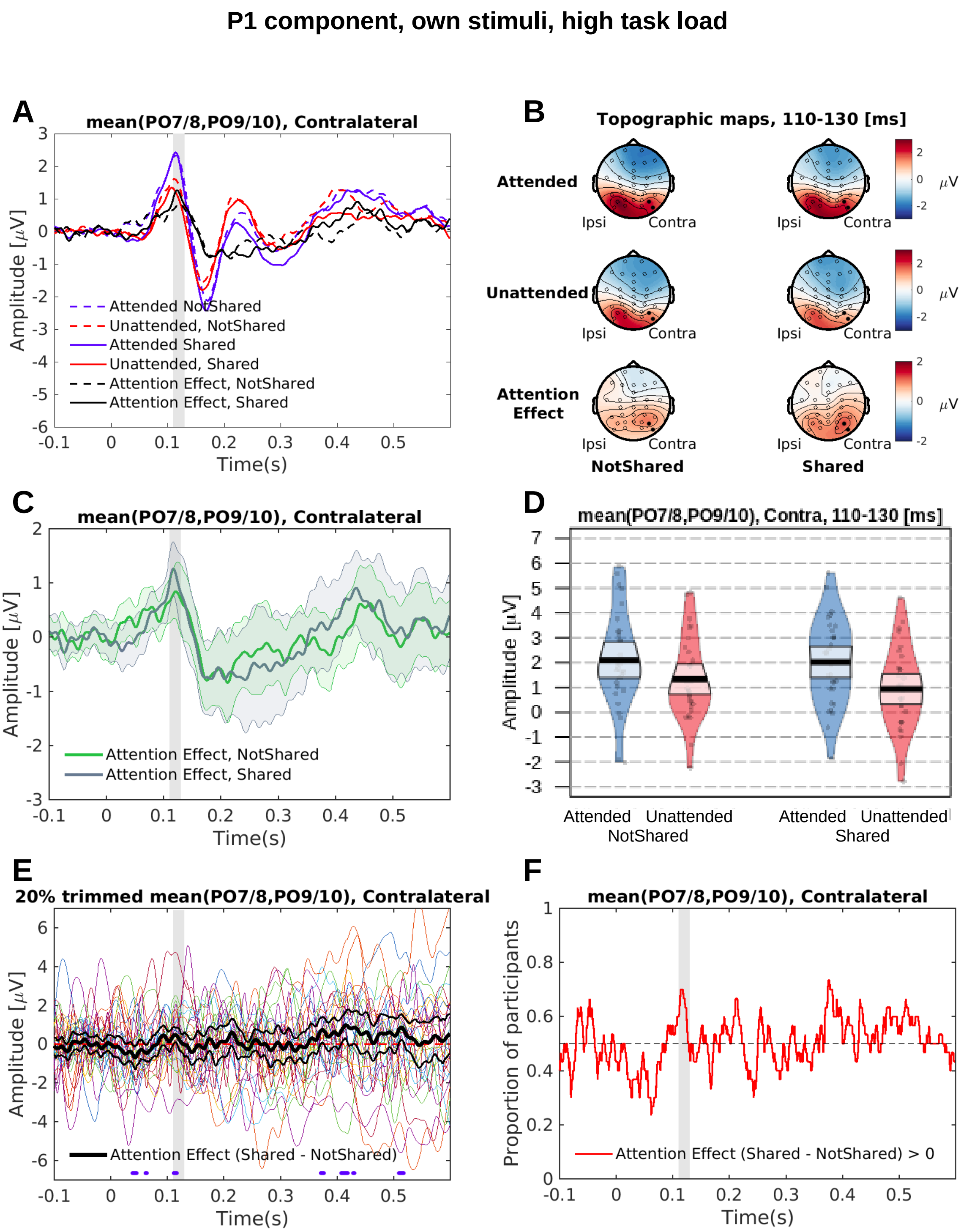


Figure 17b. P1 component for own stimuli and a high task load. A) Grand averaged ERP waveforms. The time window of interest [110-130*ms*] is displayed in grey. **B)** Average topographic maps in the time window [110-130*ms*]. For each topographic map, the right/left hemisphere show the mean amplitude for sites contralateral/ipsilateral to the stimulus location. The dark dots represent the plotted channel locations. **C)** Attention effect across attention sharing conditions. The shaded areas surrounding the waveforms represent 95% CIs. **D)** Pirateplot showing the mean ERP amplitudes for the time window of interest. The gray boxes surrounding the mean

values represent 95% CIs. **E)** 20% trimmed mean difference between the attention effect for the attention Shared and Notshared conditions. This difference is displayed with 95% CIs around the trimmed mean. The coloured waveforms show the difference (i.e., attention effect Shared minus Notshared) for each single participant. The dashed red line represents the zero [*μV*] value. The blue dots at the bottom of the plot (below the plot legend) show the time points where a significant difference (between the attention effect for the Shared vs. Notshared conditions) was obtained using yuen's tests (for dependent groups) on 20% trimmed means (at α =0.05). These values are uncorrected for multiple comparisons. The yuen's tests were computed using the function "*limo_yuend_ttest*", part of the LIMO toolbox (Pernet, Chauveau, Gaspar, & Rousselet, 2011). **F)** Proportion of participants (from 0 to 1, for every time point) showing a stronger attention effect for the attention Shared condition, compared to the Notshared scenario.The plots C, E, and F were created using a modified version of the code available at: https://github.com/GRousselet/blog/tree/master/erp_differences

P1 component, co-actor's stimuli, low task load

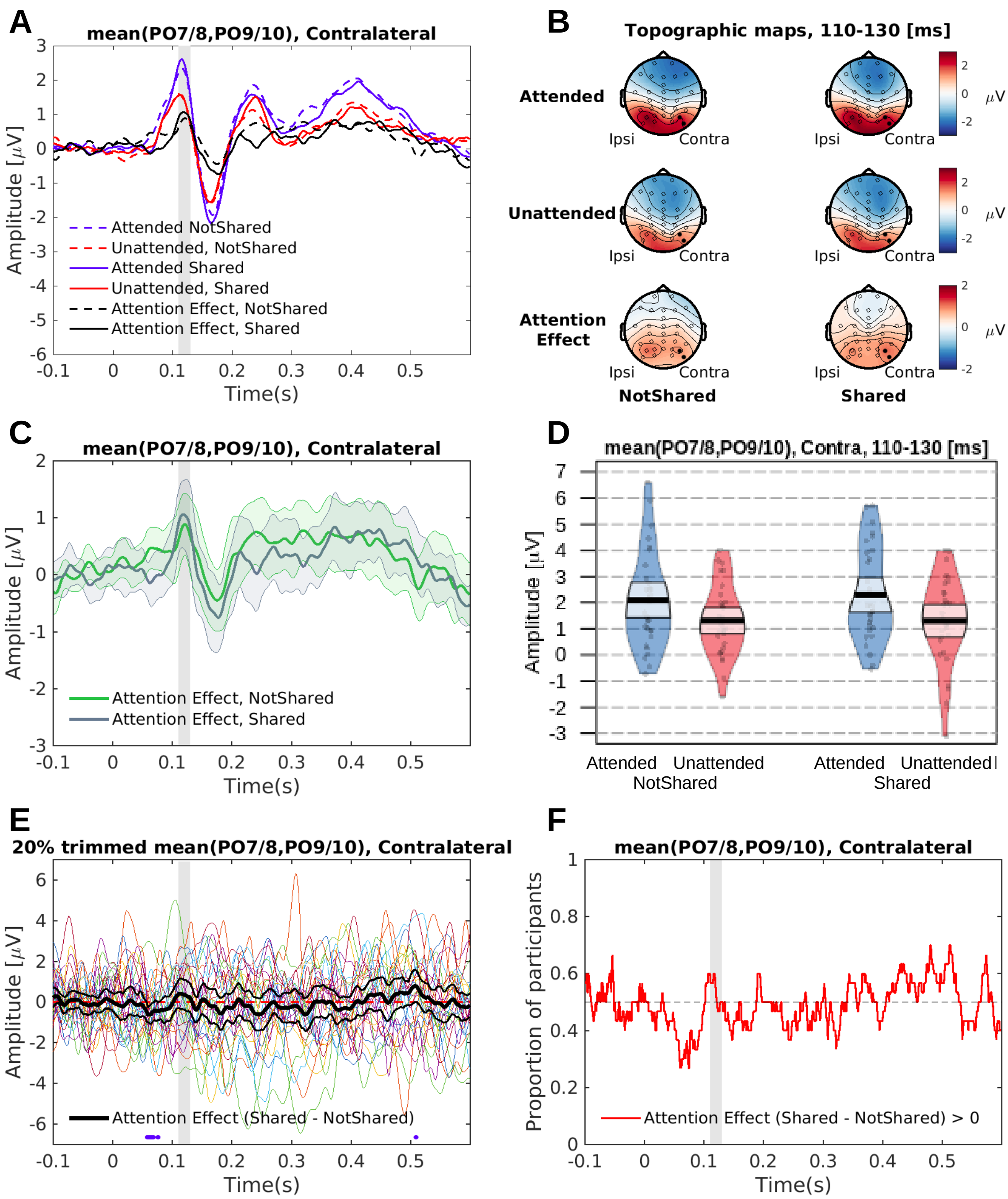


Figure 17c. P1 component for co-actor's stimuli and a low task load. A) Grand averaged ERP waveforms. The time window of interest [110-130*ms*] is displayed in grey. **B)** Average topographic maps in the time window [110-130*ms*]. For each topographic map, the right/left hemisphere show the mean amplitude for sites contralateral/ipsilateral to the stimulus location. The dark dots represent the plotted channel locations. **C)** Attention effect across attention sharing conditions. The shaded areas surrounding the waveforms represent 95% CIs. **D)** Pirateplot showing the mean

ERP amplitudes for the time window of interest. The grey boxes surrounding the mean values represent 95% CIs. **E)** 20% trimmed mean difference between the attention effect for the attention Shared and Notshared conditions. This difference is displayed with 95% CIs around the trimmed mean. The coloured waveforms show the difference (i.e., attention effect Shared minus Notshared) for each single participant. The dashed red line represents the zero [μV] value. The blue dots at the bottom of the plot (below the plot legend) show the time points where a significant difference (between the attention effect for the Shared vs. Notshared conditions) was obtained using yuen's tests (for dependent groups) on 20% trimmed means (at α =0.05). These values are uncorrected for multiple comparisons. The yuen's tests were computed using the function "*limo_yuend_ttest*", part of the LIMO toolbox (Pernet, Chauveau, Gaspar, & Rousselet, 2011). **F)** Proportion of participants (from 0 to 1, for every time point) showing a stronger attention effect for the attention Shared condition, compared to the Notshared scenario. The plots C, E, and F were created using a modified version of the code available at: https://github.com/GRousselet/blog/tree/master/erp_differences

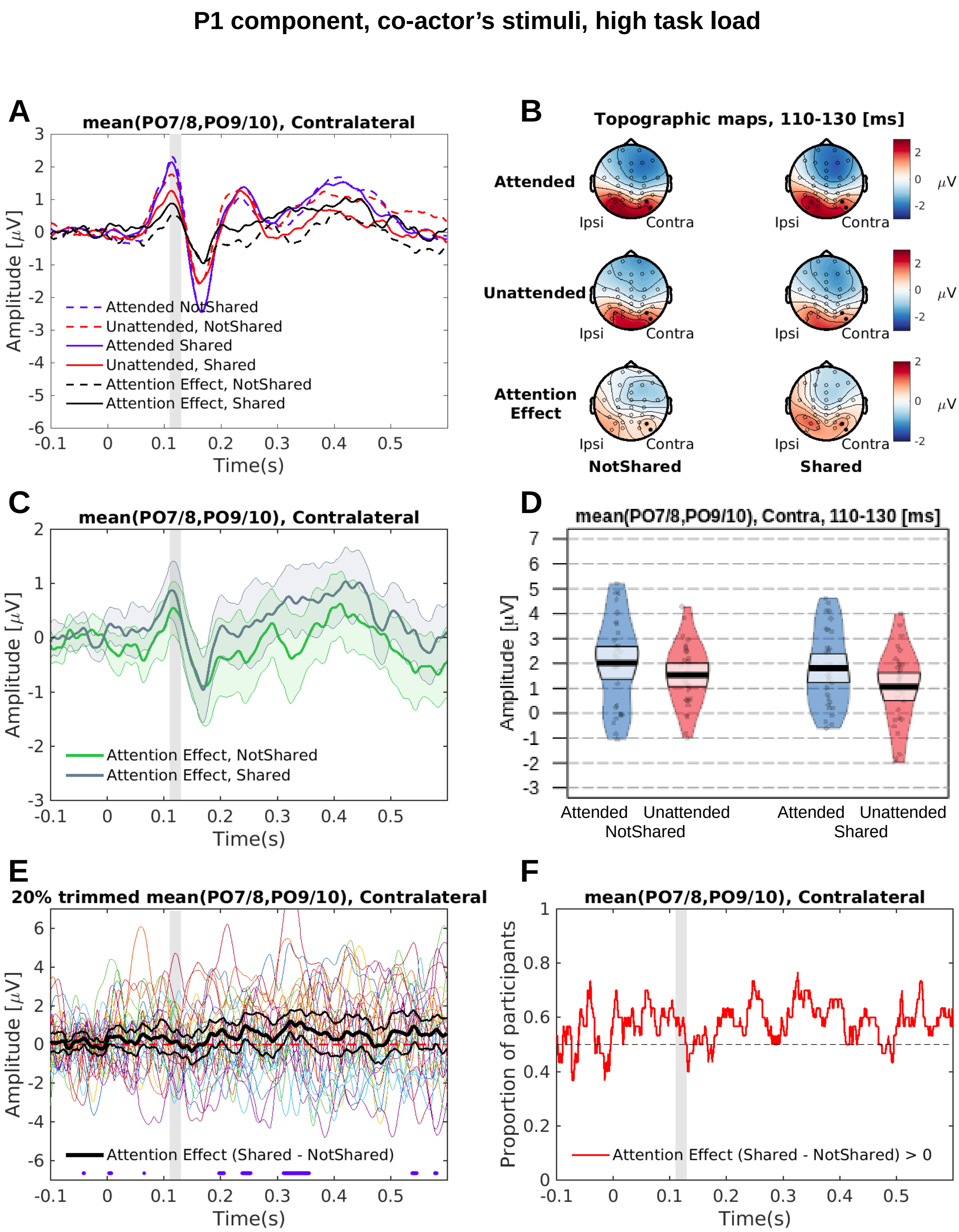


Figure 17d. P1 component for co-actor's stimuli and a high task load. A) Grand averaged ERP waveforms. The time window of interest [110-130*ms*] is displayed in grey. **B)** Average topographic maps in the time window [110-130*ms*]. For each topographic map, the right/left hemisphere show the mean amplitude for sites contralateral/ipsilateral to the stimulus location. The dark dots represent the plotted channel locations. **C)** Attention effect across attention sharing conditions. The shaded areas surrounding the waveforms represent 95% CIs. **D)** Pirateplot showing the mean

ERP amplitudes for the time window of interest. The gray boxes surrounding the mean values represent 95% CIs. **E)** 20% trimmed mean difference between the attention effect for the attention Shared and Notshared conditions. This difference is displayed with 95% CIs around the trimmed mean. The coloured waveforms show the difference (i.e., attention effect Shared minus Notshared) for each single participant. The dashed red line represents the zero [*μV*] value. The blue dots at the bottom of the plot (below the plot legend) show the time points where a significant difference (between the attention effect for the Shared vs. Notshared conditions) was obtained using yuen's tests (for dependent groups) on 20% trimmed means (at α =0.05). These values are uncorrected for multiple comparisons. The yuen's tests were computed using the function "*limo_yuend_ttest*", part of the LIMO toolbox (Pernet, Chauveau, Gaspar, & Rousselet, 2011). **F)** Proportion of participants (from 0 to 1, for every time point) showing a stronger attention effect for the attention Shared condition, compared to the Notshared scenario. The plots C, E, and F were created using a modified version of the code available at: https://github.com/GRousselet/blog/tree/master/erp_differences

4.1.4.1 N2b component

N2b mean amplitudes data in the time window of interest [240-260*ms*] were submitted to separate 3-way analysis (rmANOVA, robust method, and Bayes Factors) for each stimulus type (own vs. coactor's) (see *Table 18*). The 3-way interactions Attention (attended vs. unattended) x Sharing (attention shared vs. notshared) x Load (low vs. high perceptual load) were not significant for both the N2b responses to the own and the coactor's stimuli. In both cases, Bayes Factors (*BF10* = 0.232, and *BF10* = 0.270, respectively) suggested "moderate" support for the model without the interaction, given the data. As for P1, given that the main interest here was on the event-related responses time locked to one's own stimuli for the low perceptual load condition, and considering that a clear a-priori hypothesis was made for the interaction between attention and sharing conditions (i.e., the dual attention effect) under low perceptual load, separate 2-way analysis were run for this particular case (see also Perugini, Gallucci, & Costantini, 2018; Wahlsten, 1991; for arguments suggesting that a higher sample size may be needed to detect interaction effects in factorial designs). For clarity, separate analysis for the N2b responses to the own stimuli in high load, the partner's stimuli in low load, and the partner's stimuli in high load, were also performed. The results are presented below, and should be interpreted with caution.

Table 18. Mean N2b amplitudes in µV (with SD), at fronto-central sites (FCz, Cz), in the time window [240-260ms].

		Experimental Condition			
		Notshared		Shared	
Stimuli	Perceptual load	Attended	Unattended	Attended	Unattended
Own	Low	-0.75(2.97)	2.35(2.28)	-0.05(2.90)	2.08(2.42)
	High	-1.71(3.88)	2.39(2.54)	-1.60(4.03)	2.17(2.93)
Co-actor's	Low	0.67(2.92)	2.28(2.64)	0.79(2.66)	2.53(2.70)
	High	-0.18(3.28)	2.47(2.92)	-0.04(3.00)	2.48(3.19)

4.1.4.1.1 N2b component: own stimuli, low task load

The data regarding the N2b component for own stimuli and a high task load are summarised in *Figure 18a*. Mean ERP amplitudes data were submitted to a 2x2 repeated-measures-ANOVA with Attention (Attended vs. Unattended) and Sharing (Shared vs. Notshared) as within-subjects factors (see *Figure 18a*). The ANOVA revealed a significant main effect of Attention, F(1, 29) = 25.08, p = 2.48e-5, η^2_G =0.199, due to a typical attention effect in the N2b amplitudes. That is, larger N2b (i.e., more negative) amplitudes were obtained for the Attended stimuli ($M_{attended}$ = -0.40 µV, 95% CI [-1.42, 0.63]) than for the Unattended ones ($M_{unattended}$ = 2.21 µV, 95% CI [1.37, 3.05]). Moreover, a significant interaction Attention x Sharing, F(1, 29) = 5.82, p = .022, η^2_G =0.009, indicated that the attention effect was modulated by the attention sharing conditions. A smaller attention effect was obtained when attention was Shared by the dyad ($M_{AttEffect, Shared}$ = -2.12 µV, 95% CI [-3.24, -1.01]), than when it was NotShared ($M_{AttEffect, Notshared}$ = -3.09 µV, 95% CI [-4.26, -1.93]). This mirrors the attention reduction effect (i.e., the dual attention effect) obtained behaviourally (i.e., in RTs) in previous Experiments (e.g., Exp1, Exp3, Exp4). The main effect of Sharing was not significant, F(1, 29) = 0.78, p = .381, η^2_G =0.002.

The percentile bootstrap method on 20% trimmed means showed a significant main effect of Attention, $\hat{\psi}$ = -3.49 [-6.27, -1.99], *p* = 0, a non-significant main effect of Sharing, $\hat{\psi}$ = -0.59 [-1.65, 0.50], *p* =.295, and a non-significant interaction Attention x Sharing, $\hat{\psi}$ = -0.69 [-1.67, 0.09], *p* =.086. To address the disparity between classic

ANOVAs and the bootstrap method in relation to this 2 way interaction, the attention effect was computed (to directly examine the contrast of interest) and compared across attention sharing conditions by means of a Yuen's test for dependent trimmed means (20% trimming). This yielded a significant difference, M_{diff} = 1.08 [0.11, 2.05], Y_t (17) = 2.35, p= 0.031. For this interaction, Bayes factors (BF10 = 0.4) remained insensitive.

Post-hoc simple main effects analysis examined the effect of Sharing separately for the each of the Attention conditions. Both the classic ANOVA and the (robust) percentile bootstrap on 20% trimmed means yielded a non-significant difference between the participants N2b amplitudes to attended locations across Sharing conditions, $F(1, 29) = 3.48$, $p = .072$; $\hat{\psi}$ = -0.59 [-1.47, 0.23], $p = .170$. Similarly, no statistical difference was obtained when comparing the N2b amplitudes to unattended locations across Sharing conditions, $F(1, 29) = 1.25$, $p = .273$; $\hat{\psi}$ = 0.21 [-0.25, 0.68], $p = .376$.

4.1.4.1.2 N2b component: own stimuli, high task load

The data regarding the N2b component for own stimuli and a high task load are summarised in *Figure 18b*. The 2x2 ANOVA showed a significant main effect of Attention, F(1, 29) = 24.47, p = 2.94e-5, η^2_G =0.257, due to stronger N2b amplitudes evoked by the Attended stimuli ($M_{attended}$ = -1.66 μV, 95% CI [-3.09, -0.22]) than by the Unattended ones ($M_{unattended}$ = 2.28 μV, 95% CI [1.31, 3.25]). The main effect of Sharing was not significant, F(1, 29) = 0.04, p = .829, nor the interaction Attention x Sharing, F(1, 29) = 0.44, p = .511.

The outcome of the robust method mirrored the ANOVA results. The percentile bootstrap on 20% trimmed means yielded a significant main effect of Attention, $\hat{\psi}$ = -6.78 [-10.1, -3.87], $p = 0$, a non-significant main effect of Sharing, $\hat{\psi}$ = 0.14 [-0.59, 0.87], p =.689, and a non-significant interaction Attention x Sharing, $\hat{\psi}$ = -0.19 [-1.27, 0.83], p =.702. Bayes factors for this interaction (*BF10* = 0.274) suggested "moderate" support for the model without the interaction, given the data.

4.1.4.1.3 N2b component: co-actor's stimuli, low task load

The data regarding the N2b component for the co-actor's stimuli and a low task load are summarised in *Figure 18c*. The ANOVA yielded a significant main effect of Attention, F(1, 29) = 10.60, p = .003, η_G^2 =0.089, due to a larger N2b for the Attended stimuli ($M_{attended}$ = 0.73 μV, 95% CI [-0.24, 1.71]) than for the Unattended ones ($M_{unattended}$ = 2.41 μV, 95% CI [1.45, 3.37]). The main effect of Sharing was not significant, F(1, 29) = 0.81, p = .814, nor the interaction Attention x Sharing, F(1, 29) = 0.07, p = .800.

The results after computing the percentile bootstrap on 20% trimmed means pointed in the same direction. This method yielded a significant main effect of Attention, $\hat{\psi}$ = -2.80 [-4.51, -1.32], *p* = 8e-4, a non-significant main effect of Sharing, $\hat{\psi}$ = -0.41 [-1.36, 0.61], *p* =.431, and a non-significant interaction Attention x Sharing, $\hat{\psi}$ = -0.26 [-0.72, 1.25], *p* =.604. Bayes factors for this interaction (*BF10* = 0.261) suggested "moderate" support for the model without the interaction, given the data.

4.1.4.1.4 N2b component: co-actor's stimuli, high task load

The data regarding the N2b component for the co-actor's stimuli and a high task load are summarised in *Figure 18d*. The ANOVA showed a significant main effect of Attention, F(1, 29) = 22.47, p = 5.22e-5, η_G^2 =0.152, due to a typical attention effect in the N2b amplitudes, with stronger N2b responses for the Attended stimuli ($M_{attended}$ = -0.11 μV, 95% CI [-1.18, 0.97]) than for the Unattended ones ($M_{unattended}$ = 2.47 μV, 95% CI [1.39, 3.56]). The main effect of Sharing was not significant, F(1, 29) = 0.06, p = .804, nor the interaction Attention x Sharing, F(1, 29) = 0.05, p = .820.

*T*he percentile bootstrap on 20% trimmed means mirrored the ANOVA results. It yielded a significant main effect of Attention, $\hat{\psi}$ = -4.85 [-7.18, -2.75], *p* = 0, a non-significant main effect of Sharing, $\hat{\psi}$ = -0.14 [-1.46, 1.23], *p* =.827, and a non-significant interaction Attention x Sharing, $\hat{\psi}$ = -0.40 [-1.32, 0.80], *p* =.482. Bayes factors for this interaction (*BF10* = 0.262) suggested "moderate" support for the model without the interaction, given the data.

N2b component, own stimuli, low task load

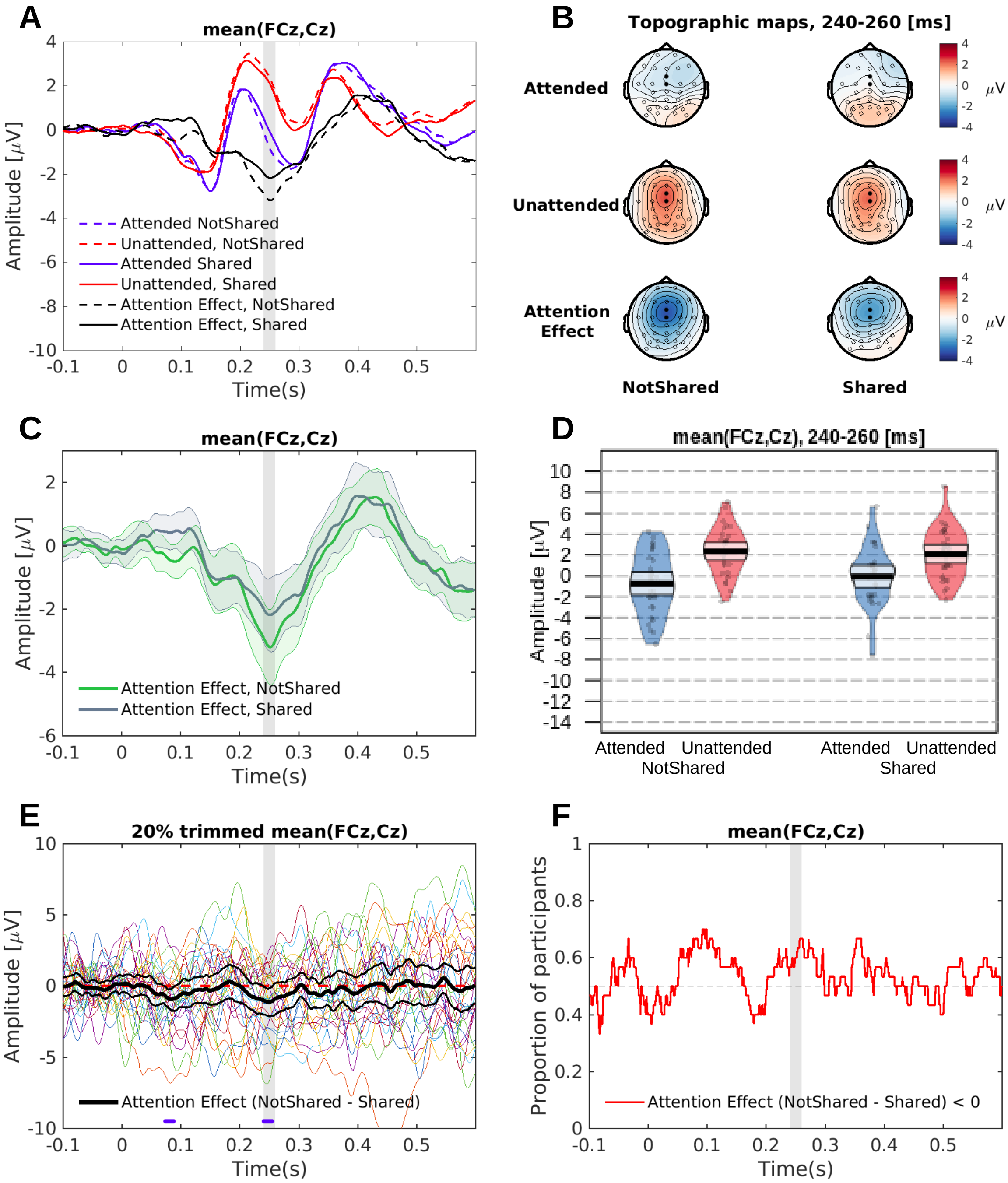


Figure 18a. N2b component for own stimuli and a low task load. A) Grand averaged ERP waveforms. The time window of interest [240-260*ms*] is displayed in grey. **B)** Average topographic maps in the time window [240-260*ms*]. The dark dots represent the plotted channel locations. **C)** Attention effect across attention sharing conditions. The shaded areas surrounding the waveforms represent 95% CIs. **D)** Pirateplot showing the mean ERP amplitudes for the time window of interest. The gray boxes surrounding the mean values represent 95% CIs. **E)** 20% trimmed mean

difference between the attention effect for the attention Notshared and Shared conditions. This difference is displayed with 95% CIs around the trimmed mean. The coloured waveforms show the difference (i.e., attention effect Notshared minus Shared) for each single participant. The dashed red line represents the zero [*μV*] value. The blue dots at the bottom of the plot (below the plot legend) show the time points where a significant difference (between the attention effect for the Shared vs. Notshared conditions) was obtained using yuen's tests (for dependent groups) on 20% trimmed means (at α=0.05). These values are uncorrected for multiple comparisons. The yuen's tests were computed using the function "*limo_yuend_ttest*", part of the LIMO toolbox (Pernet, Chauveau, Gaspar, & Rousselet, 2011). **F)** Proportion of participants (from 0 to 1, for every time point) showing a stronger attention effect for the attention Notshared condition, compared to the shared scenario. The plots C, E, and F were created using a modified version of the code available at: https://github.com/GRousselet/blog/tree/master/erp_differences

N2b component, own stimuli, high task load

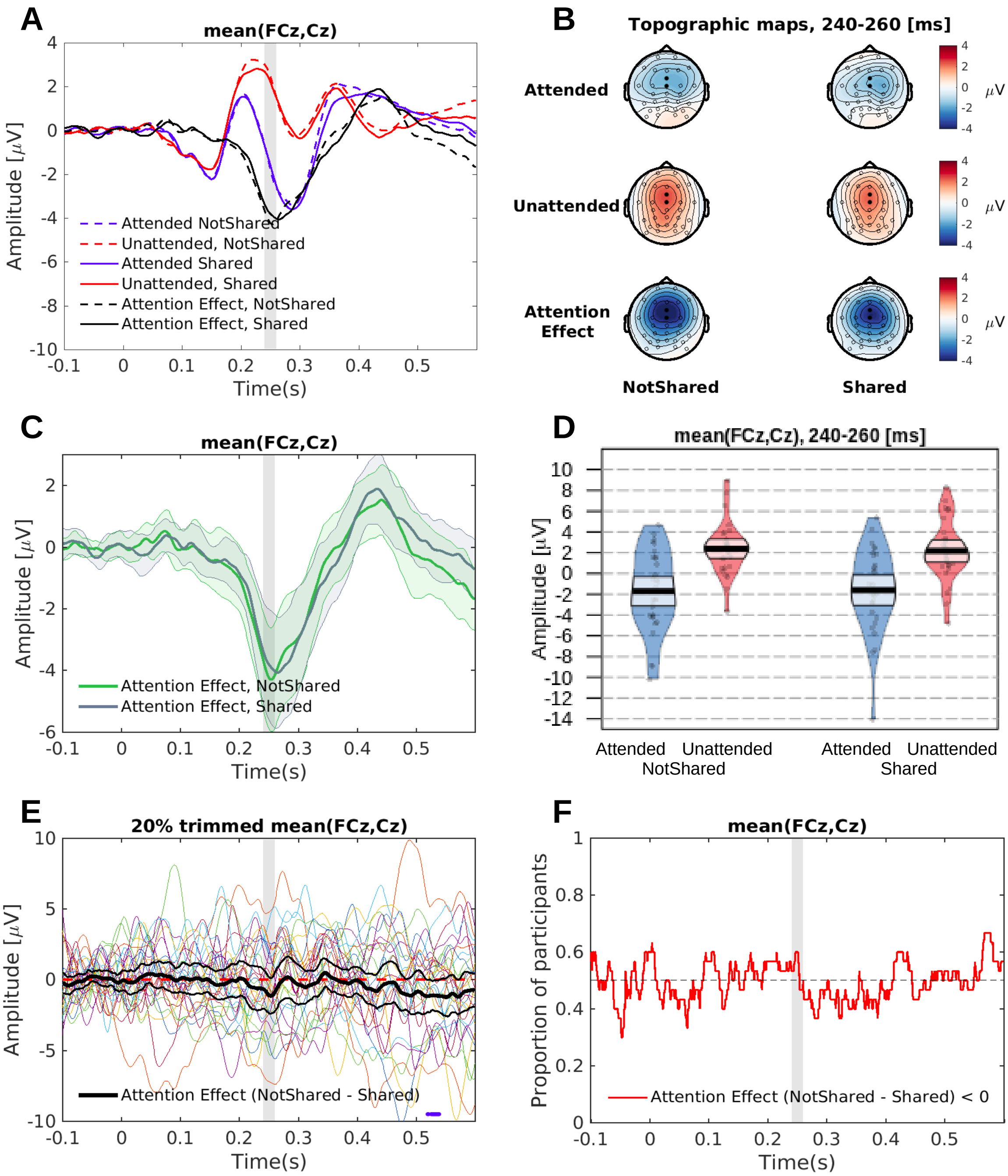


Figure 18b. N2b component for own stimuli and a high task load. A) Grand averaged ERP waveforms. The time window of interest [240-260*ms*] is displayed in grey. **B)** Average topographic maps in the time window [240-260*ms*]. The dark dots represent the plotted channel locations. **C)** Attention effect across attention sharing conditions. The shaded areas surrounding the waveforms represent 95% CIs. **D)** Pirateplot showing the mean ERP amplitudes for the time window of interest. The gray boxes surrounding the mean values represent 95% CIs. **E)** 20% trimmed mean

difference between the attention effect for the attention Notshared and Shared conditions. This difference is displayed with 95% CIs around the trimmed mean. The coloured waveforms show the difference (i.e., attention effect Notshared minus Shared) for each single participant. The dashed red line represents the zero [*μV*] value. The blue dots at the bottom of the plot (below the plot legend) show the time points where a significant difference (between the attention effect for the Shared vs. Notshared conditions) was obtained using yuen's tests (for dependent groups) on 20% trimmed means (at α=0.05). These values are uncorrected for multiple comparisons. The yuen's tests were computed using the function "*limo_yuend_ttest*", part of the LIMO toolbox (Pernet, Chauveau, Gaspar, & Rousselet, 2011). **F)** Proportion of participants (from 0 to 1, for every time point) showing a stronger attention effect for the attention Notshared condition, compared to the shared scenario. The plots C, E, and F were created using a modified version of the code available at: https://github.com/GRousselet/blog/tree/master/erp_differences

N2b component, co-actor's stimuli, low task load

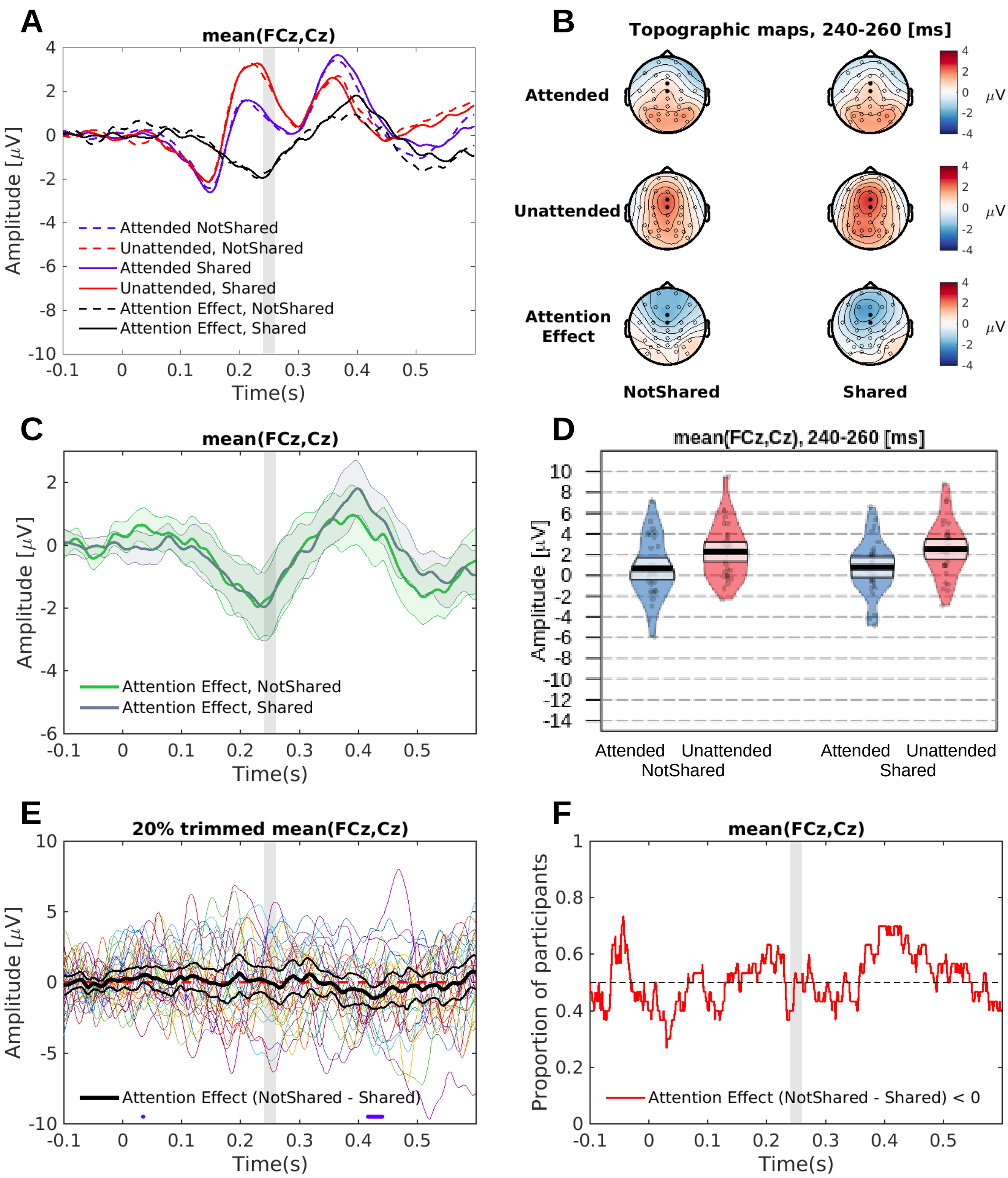


Figure 18c. N2b component for co-actor's stimuli and a low task load. A) Grand averaged ERP waveforms. The time window of interest [240-260*ms*] is displayed in grey. **B)** Average topographic maps in the time window [240-260*ms*]. The dark dots represent the plotted channel locations. **C)** Attention effect across attention sharing conditions. The shaded areas surrounding the waveforms represent 95% CIs. **D)** Pirateplot showing the mean ERP amplitudes for the time window of interest. The gray boxes surrounding the mean values represent 95% CIs. **E)** 20% trimmed mean difference between the attention effect for the attention Notshared and Shared

conditions. This difference is displayed with 95% CIs around the trimmed mean. The coloured waveforms show the difference (i.e., attention effect Notshared minus Shared) for each single participant. The dashed red line represents the zero [*μV*] value. The blue dots at the bottom of the plot (below the plot legend) show the time points where a significant difference (between the attention effect for the Shared vs. Notshared conditions) was obtained using yuen's tests (for dependent groups) on 20% trimmed means (at α=0.05). These values are uncorrected for multiple comparisons. The yuen's tests were computed using the function "*limo_yuend_ttest*", part of the LIMO toolbox (Pernet, Chauveau, Gaspar, & Rousselet, 2011). **F)** Proportion of participants (from 0 to 1, for every time point) showing a stronger attention effect for the attention Notshared condition, compared to the shared scenario. The plots C, E, and F were created using a modified version of the code available at: https://github.com/GRousselet/blog/tree/master/erp_differences

N2b component, co-actor's stimuli, high task load

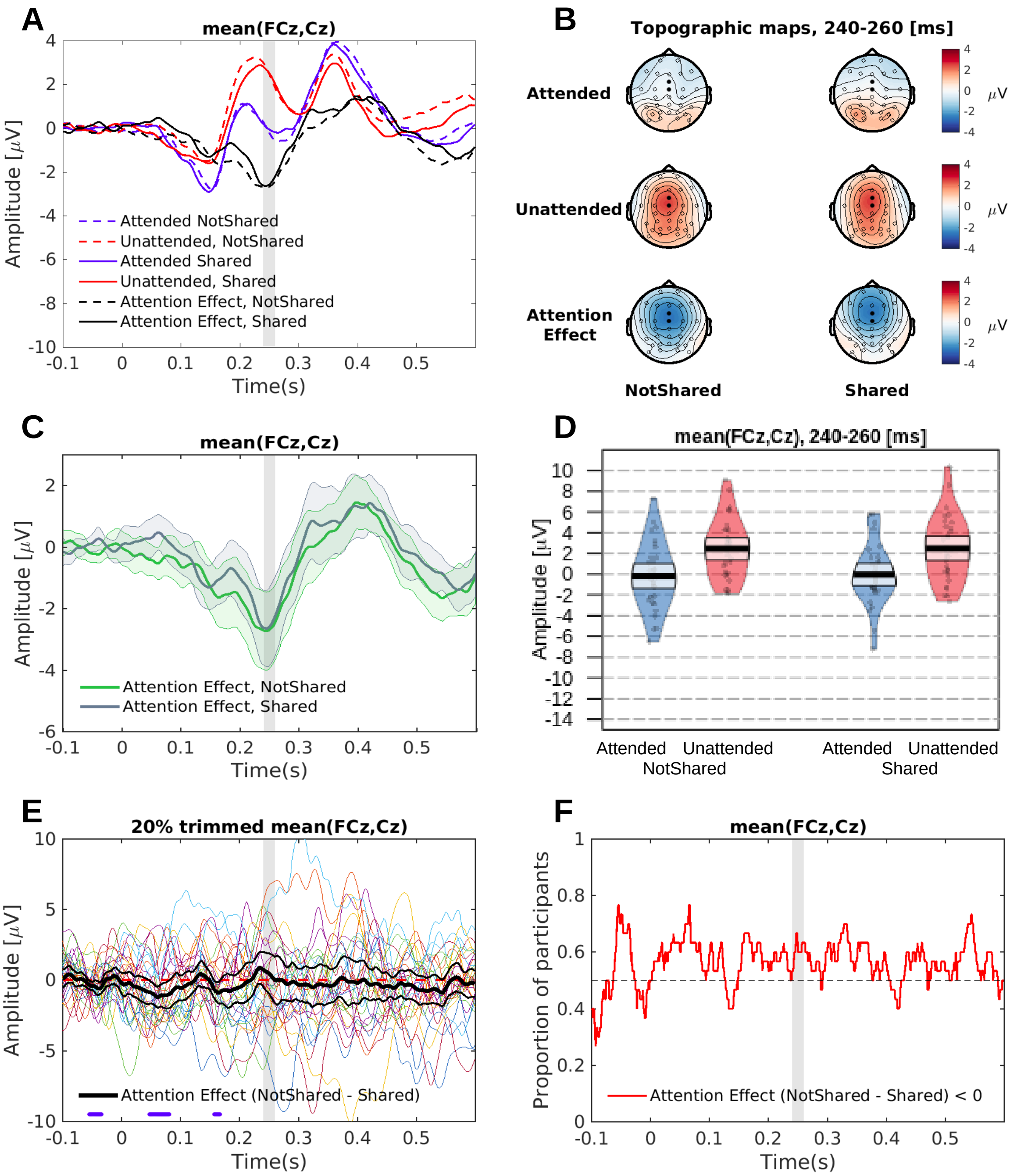


Figure 18d. N2b component for co-actor's stimuli and a high task load. A) Grand averaged ERP waveforms. The time window of interest [240-260*ms*] is displayed in grey. **B)** Average topographic maps in the time window [240-260*ms*]. The dark dots represent the plotted channel locations. **C)** Attention effect across attention sharing conditions. The shaded areas surrounding the waveforms represent 95% CIs. **D)** Pirateplot showing the mean ERP amplitudes for the time window of interest. The gray boxes surrounding the mean values represent 95% CIs. **E)** 20% trimmed mean difference between the attention effect for the attention Notshared and Shared

conditions. This difference is displayed with 95% CIs around the trimmed mean. The coloured waveforms show the difference (i.e., attention effect Notshared minus Shared) for each single participant. The dashed red line represents the zero [*μV*] value. The blue dots at the bottom of the plot (below the plot legend) show the time points where a significant difference (between the attention effect for the Shared vs. Notshared conditions) was obtained using yuen's tests (for dependent groups) on 20% trimmed means (at $\alpha=0.05$). These values are uncorrected for multiple comparisons. The yuen's tests were computed using the function "*limo_yuend_ttest*", part of the LIMO toolbox (Pernet, Chauveau, Gaspar, & Rousselet, 2011). **F)** Proportion of participants (from 0 to 1, for every time point) showing a stronger attention effect for the attention Notshared condition, compared to the shared scenario. The plots C, E, and F were created using a modified version of the code available at:
https://github.com/GRousselet/blog/tree/master/erp_differences

4.1.4.1 Correlation analysis: P1 component ~ N2b component

To examine whether the processes reflected by P1 and N2b were associated, Spearman's correlation were run between the dual attention effects measured for each of these event-related components (this was done for the own stimuli in the low perceptual load condition). This correlation was not significant, $r_s = .171$, $p = .366$.

4.1.5 Follow-up analysis: Investigating the role of brain oscillations in sensory processing and cognitive control

Event-related potentials show one aspect of neural activity, the so-called evoked responses. This activity is both time-locked and phase-locked (or phase aligned) to a particular event of interest (e.g., the onset of a stimulus, a response, etc), and is typically studied in the time-domain. However, it has been argued that ERPs actually show little of the information contained in EEG data (Cohen, 2014a), and that instead, additional valuable information regarding neural processes and oscillations can be obtained by examining induced neural activity (i.e., neural activity time-locked but non-phase-locked to an event of interest) and its evolution over time (Cohen, 2014a). Information about induced oscillations can not be captured by using the event-related potentials method (Cohen, 2014a, 2018; Herrmann et al., 2014). This occurs because the non-phase-locked activity is cancelled out when averaging trial level responses along the event-related analysis (Luck, 2014). Time-frequency analysis or time-frequency-representations (Cohen, 2014a, 2018; Herrmann et al., 2014) instead, allow the investigation of the induced neural oscillations, their temporal evolution, and the way they are modulated by different cognitive processes (role in human cognition) (Cohen, 2014a).

Electrophysiological signals from populations of neurons are characterised by oscillatory activity in a broad range of frequencies (Buzsáki, 2004, 2006; Wang, 2010). This rhythmic activity has been deemed as a fundamental mechanism behind the coordination of the information flow in the brain (Fries, 2005, 2015; Siegel, Donner, & Engel, 2012), supporting a wide range of cognitive processes (Buzsáki, 2006; James F. Cavanagh & Frank, 2014; Fries, 2005, 2015; Helfrich, Huang, Wilson, & Knight, 2017; Helfrich & Knight, 2016; Jensen & Mazaheri, 2010; Jensen, Spaak, & Zumer, 2019; Sauseng et al., 2005; Siegel et al., 2012). Traditionally, brain oscillations have been studied focusing on several characteristic frequency ranges: delta (~ 2-4 Hz), theta (~ 4-8 Hz), alpha (~ 8-14 Hz), beta (~ 15-30 Hz), and gamma (~ 30-80 Hz) (although there are no precise boundaries for defining these frequency bands; Cohen, 2014a , 2018). The current section follows-up the event-related potentials results presented above by investigating oscillatory activity in the alpha and theta frequency bands, considered neural markers of visual attention (Sauseng et al., 2005) and cognitive control (Cavanagh & Frank, 2014) respectively. Time-frequency analysis were employed for this purpose (see *“Time-frequency representations data analysis”* section below).

Importantly, the analysis carried out on the event-related responses to the own stimuli in the high perceptual load condition, to the partner’s stimuli in the low perceptual load, and to the partner’s stimuli in the high perceptual load, did not show any modulation in attention performance by the attention sharing conditions (i.e., no interaction Attention x Sharing). Considering this, the subsequent time-frequency follow-up analysis addressed exclusively the neural responses to one’s own stimuli for the low perceptual load condition. As a reminder, this condition was of central interest when planning the current experiment.

4.1.5.1 Alpha band oscillations

Almost a century ago, Hans Berger first observed and defined the alpha rhythm (Berger, 1929), the first electrophysiological signal recorded in the human brain. The initial observations showed parieto-occipital oscillatory patterns that were attenuated by opening the eyes, and reduced by attentive states (Adrian & Matthews, 1934a, 1934b; Berger, 1929). These observations were initially taken to suggest that alpha oscillations represented an ‘idling’ rhythm of the brain (Adrian & Matthews, 1934b). More recent research however, has shown that alpha oscillations actively contribute to human brain function, as an inhibitory rhythm (see da Silva, 2013 for a review). According to this view, alpha oscillations are considered as a marker of cortical inhibition (Klimesch, Sauseng, & Hanslmayr, 2007; Palva & Palva, 2007; Pfurtscheller, 2003; Ray & Cole, 1985; Sauseng et al., 2005; Thut, 2006), and a decrease in their amplitude has been linked to increased cortical activation or cortical excitability (Palva & Palva, 2007; Pfurtscheller, 2001).

Alpha oscillations are known to covary with visual attentional changes (see Clayton, Yeung, & Cohen Kadosh, 2018). In visual attention tasks, an alpha suppression (i.e., a reduction in the amplitude/power of the oscillatory activity) in parieto-occipital areas is obtained in response to visual stimuli or visual cues (e.g., Bauer, Stenner, Friston, & Dolan, 2014; Fan et al., 2007), or in preparation period prior to their appearance (e.g., Kelly, Lalor, Reilly, & Foxe, 2006; Sauseng et al., 2005; Thut, 2006). This suppression is typically stronger in regions contralateral than ipsilateral to the attended visual hemifield (Sauseng et al., 2005). Following the cortical inhibition framework, the reduced contralateral alpha is thought to reflect a release of the cortical inhibition (or enhanced cortical excitability) in visual areas that would actively process the attended spatial locations, facilitating the subsequent cortical handling of visual inputs (Sauseng et al., 2005). The increased alpha amplitude at ipsilateral locations on the other hand, has been associated to an enhanced inhibition of cortical regions processing task-irrelevant information present in the ipsilateral hemifield (Kelly, Lalor, Reilly, & Foxe, 2006; Worden, Foxe, Wang, & Simpson, 2000).

The debate is still open regarding the origins of these oscillations in the human brain. Although no final consensus has been achieved in relation to the generators of this rhythm, current views point towards both thalamic and cortical contributions (Halgren et al., 2019). The calcarine fissure, secondary visual areas, and the parietal cortex have been shown to be involved in the generation of posterior alpha oscillations related to visual attention (Chapman, Ilmoniemi, Barbanera, & Romani, 1984; Ciulla & Takeda, 1999; Thut, 2006). However, rhythms in the same frequency range have been identified in several cortical regions, and linked to multiple processes beyond the visual domain (see Clayton et al., 2018 for a review; see also Sadaghiani & Kleinschmidt, 2016).

Furthermore, alpha band oscillations seem to support not only local attentional processing, but also information exchange across regions in the brain (Fries, 2015; Halgren et al., 2019; Patten, Rennie, Robinson, & Gong, 2012; von Stein & Sarnthein, 2000). Indeed, alpha oscillations have been linked to top-down processing and deemed as a top-down rhythm (Benedek, Bergner, Können, Fink, & Neubauer, 2011; Doesburg, Bedo, & Ward, 2016; Halgren et al., 2019; von Stein, Chiang, & Konig, 2000), and may be closely related to cognitive control networks in order to implement inhibitory control (e.g., through a widespread increase in alpha power), facilitate local information processing (e.g., through focal alpha desynchronisation), and regulate long-range information exchange (e.g., by changing alpha band phase-locking between distant regions) (see Sadaghiani & Kleinschmidt, 2016). In the case of visuospatial attention research, it has been shown that the typically stronger alpha power reduction measured at posterior regions contralateral vs. ipsilateral (to the attended stimulus or hemifield) is usually accompanied by a stronger phase coupling between pre-frontal regions and the contralateral posterior sites than to the ipsilateral ones, suggesting a potential top-down influence from pre-frontal areas in the control of visual attention (e.g., Sauseng et al., 2005).

4.1.5.2 Alpha band oscillations in the current experiment

Time-frequency representations of power in the alpha frequency range were examined, as well as functional connectivity in the alpha band. The aim was to examine whether posterior alpha power and alpha band functional connectivity between prefrontal and parieto-occipital sites, were modulated by the attention sharing conditions (i.e., if they changed when participants in a dyad shared or not their attentional locus) while participants performed the dual attention task. As discussed above, these follow-up analysis were performed exclusively on the EEG data corresponding to the processing of the own stimuli, in the low task load condition (i.e., the easy size discrimination task) (see also the section *“Time-frequency representations data analysis”*).

For the posterior alpha, the attention effect is typically defined as the difference between the power at contralateral and ipsilateral sites. Following previous research outcomes (e.g., Sauseng et al., 2005), a stronger alpha reduction is expected contralateral than ipsilateral to the attended hemifield. If the dual attention effect reported in the previous behavioural experiments is reflected in the posterior alpha suppression, a reduced attention effect (as measured in the posterior alpha power) would be expected when the dyads shared the attentional locus than when their locus of attention differed. This outcome would be reflected in a two-way interaction between Attention (alpha power Contralateral vs. Ipsilateral to the attended stimuli) and Sharing (attention Shared vs. Notshared) factors.

As introduced above, the analysis here performed did not focus exclusively on alpha oscillatory power. The current section also examined whether the functional connectivity strength (in the alpha band) between prefrontal and parieto-occipital regions was modulated by attention sharing conditions. As introduced above, alpha is considered to be involved in long-range information exchange in the brain (Fries, 2015; Halgren et al., 2019; Patten, Rennie, Robinson, & Gong, 2012; von Stein & Sarnthein, 2000), likely in a top-down manner (e.g., Halgren et al., 2019). In the current data, following Sauseng et al. (2005), a stronger functional connectivity would be expected between prefrontal and parieto-occipital areas contralateral than ipsilateral to the attended stimulus. This difference in the connectivity respect to contralateral and ipsilateral areas represents here the attention effect. As for the alpha power, a two-way interaction Attention x Sharing may suggest a potential top-down guidance of attention from prefrontal areas as a potential mechanism behind the attention reduction characterising the dual attention effect. If inhibitory feedback derived from cognitive control is behind the dual attention effect, a stronger attention effect in alpha band functional connectivity would be expected when the dyad shared the attended spatial locations.

4.1.5.3 Theta band oscillations

First described by Grey Walter in 1936 (Walter, 1936), this oscillatory activity around ~6 Hz has been linked to sleep, brain disease and multiple cognitive operations (Hari & Puce, 2017). Of particular relevance for the current research project is the link between mid-frontal theta oscillations and cognitive control (see Cavanagh & Frank, 2014 for a review). An increase in mid-frontal theta power has been shown to be the brain's neural response when processing conflicting or incongruent information (Cohen, 2014; Cohen & Cavanagh, 2011; Cohen & Donner, 2013; Cohen & Ridderinkhof, 2013; López-García et al., 2019; Nigbur, Ivanova, & Stürmer, 2011; Pastötter, Hanslmayr, & T. Bäuml, 2010). Mid-frontal theta has been observed in tasks where there is a conflict among competing responses or existing representations. In this line, it has been related to error monitoring/resolution (e.g., Cavanagh, Cohen, & Allen, 2009; Cohen & Donner, 2013; Luu, Tucker, & Makeig, 2004; Trujillo & Allen, 2007), response inhibition (e.g., Andreu et al., 2019; Funderud et al., 2012; Kamarajan et al., 2004), and task interference (e.g., Nigbur et al., 2011), among others (see Cavanagh & Frank, 2014).

Although the causal role played by midfrontal theta in cognitive control processes has been demonstrated (van Driel, Sligte, Linders, Elport, & Cohen, 2015), the way this frontal rhythm is originated and its functional significance remain unclear (Cohen, 2014b, 2017). Some research outcomes have shown that midfrontal theta is generated in the mPFC, particularly in the ACC (e.g., Ishii et al., 2014; see also Cavanagh & Frank, 2014). However, the way in which theta oscillations may aid the pre-frontal neural circuitry to support and/or implement conflict detection and control is unknown (Cohen, 2014b).

The cognitive processes in which mid-frontal theta oscillations are implicated echo ERP findings related to the N2b component (see the introductory section of the current chapter). Both frontal theta and the N2b are considered markers of cognitive control, and both have been tracked down to ACC origins (Crottaz-Herbette & Menon, 2006; Ishii et al., 2014; Van Veen & Carter, 2002). However, it has been shown that these two neural responses may reflect different aspects of control processes and are typically not correlated (Cohen, 2018; Cohen & Donner, 2013). In addition, although both the N2b and theta do correlate with reaction times, this correlation is further modulated by the task condition exclusively in the case of theta oscillations (Cohen & Donner, 2013). A significantly stronger correlation between theta (than between N2b) and RTs is obtained when comparing high vs. low-conflict trials (Cohen, 2018; Cohen & Donner, 2013). This has been taken to suggest that the N2b may reflect general task processing, while theta may be related to the specific processing performed to detect and control conflicts (Cohen, 2018; Cohen & Donner, 2013). Importantly, mid-frontal theta is considered to be more sensitive and to have a higher statistical power that the N2b (Cohen, 2014b; Cohen & Donner, 2013), which makes the investigation of these oscillations in the current data particularly appealing.

4.1.5.4 Theta band oscillations in the current experiment

In the current data, the N2b ERP component results suggested an involvement of cognitive control in the reduced attention effect obtained behaviourally when dyad's shared the attended locations in the task. Mid-frontal theta oscillations are known to more reliably reflect a link to cognitive control processes than the N2b component (Cohen, 2018; Cohen & Donner, 2013). Thus, if cognitive control indeed plays a relevant role in the dual attention task, a modulation in the theta power by the attention sharing conditions is expected. Previous literature in relation to theta oscillations and cognitive control has typically shown an increase in theta power for the most conflicting condition (e.g., Cavanagh & Frank, 2014). Therefore, in the current data a larger theta-power attention effect was be expected when participants shared the attended spatial locations in the dual attention task (i.e., the most conflicting condition according to the previous results). The attention effect was here defined as the power difference in response to attended and unattended stimuli (theta power for attended minus unattended). Accordingly, a two-way interaction Attention x Sharing was predicted.

4.1.6 Time-frequency representations data analysis

The time-frequency representations computation was implemented in MATLAB 8.3 (MathWorks Inc. Natick, MA), using the Fieldtrip toolbox (Oostenveld et al., 2011) and customized scripts. The data pre-processing was performed using the EEGLAB toolbox (Delorme & Makeig, 2004), and the ERPLAB toolbox (Lopez-Calderon & Luck, 2014). The re-referenced and filtered (1-40Hz; Butterworth filters, order 4) EEG data was segmented in epochs [-0.8s to 1s] time-locked to the stimulus onset. A peak-to-peak threshold of ±100 µV was used for artifact rejection. Seven participants were excluded for having more than 50% of their data rejected at this stage. The EEG data for non-target stimuli from the remaining 31 participants were analysed.

4.1.6.1 Posterior alpha and mid-frontal theta power

Time-frequency representations of power were computed using Hanning-tapered Short-Time Fourier Transforms (STFT) with a frequency-dependant window length (3 cycles). This was done for the full epoch length (-800 to 1000ms) in the frequency range 2-40Hz (with steps of 0.5Hz). For the own non-target stimuli, induced power relative (dB) to the baseline period [-0.3 to -0.1s] was calculated. Statistical analyses were performed on the posterior alpha band power (8-14Hz), and mid-frontal theta power (5-7Hz; see the footnote for details about this choice)[7]. As for the ERP analysis, the electrode sites and time windows of interest were determined using collapsed localisers (Luck, 2014; Luck & Gaspelin, 2017). In this way, the posterior alpha power was quantified by measuring the average mean EEG amplitude at parieto-occipital sites (PO7/8, O1/2) contralateral and ipsilateral to the attended stimulus location, in the time window [250-350*ms*]. For the mid-frontal theta, the power at fronto-central sites (Fz, FCz) was evaluated in the time window [300-400ms]. The grand-averaged waveforms are presented in *Figure 19.*

4.1.6.2 Alpha band functional connectivity

The imaginary part of coherence (iCoh) (Nolte et al., 2004) in the alpha band was computed to examine sensor-level functional connectivity between prefrontal and posterior areas. This method is robust to volume conduction effects (Bastos & Schoffelen, 2016; Nolte et al., 2004, 2008; Nolte & Marzetti, 2019; Shahbazi, Ewald,

7 Here the investigation of the theta band oscillations was constrained to the 5-7Hz frequency range. This was done due to limitations in the current experimental design. The current trial length, although prototypical for ERP analysis, is not ideal for time-frequency analysis, specially if interested in the lower side of the spectrum (e.g., the theta frequency range) (Cohen, 2014a). The current trial length limits the range of frequencies that could be studied without contamination from neighbour trials, as well as the choice of a safe baseline period (Cohen, 2014a). These issues are exacerbated for lower frequencies. For this reason, only oscillations above 5Hz were considered for analysis, instead of the full theta frequency range.

Ziehe, & Nolte, 2010). That is, it is not affected by the instantaneous propagation of electromagnetic signals from simultaneously active sources in the brain, which is the most relevant confound when examining sensor-level intra-brain connectivity in M/EEG (Nolte & Marzetti, 2019). As a side effect worth mentioning, the method does not capture any real synchronised activity occurring instantaneously (i.e., in a completely symmetric and simultaneous way) (Bastos & Schoffelen, 2016; Nolte et al., 2004, 2008; Nolte & Marzetti, 2019; Shahbazi, Ewald, Ziehe, & Nolte, 2010).

Here, the imaginary part of coherence was calculated for the conditions of interest (i.e., ContraIpsi: contralateral vs. ipsilateral to the attended stimulus location; Sharing: attention shared vs. notshared by the dyad), computed separately for the interactions between FCz and PO7/8, and between FCz and O1/2. These were subsequently averaged (i.e., the average between iCoh(FCz-PO7/8) and iCoh(FCz-O1/2) was calculated). The connectivity values were baseline corrected (absolute baseline) to the time range [-0.3 to -0.1s]. As for the previous ERP and TFR analysis, the time-window of interest (100ms to 200ms) was defined using collapsed localisers (Luck, 2014; Luck & Gaspelin, 2017). The grand-averaged connectivity values are presented in *Figure 19c*.

4.1.7 Results (TFRs)

As introduced above, the follow-up analysis here presented addressed exclusively the neural responses to own stimuli in the low perceptual load condition. As for the ERPs, the statistical analyses were performed using R (version '1.1.456') and RStudio (RStudio Team, 2016). Mean power (or imaginary coherence values) data were analysed employing classic ANOVAs, the percentile bootstrap method on 20% trimmed means (Wilcox, 2012), and Bayes factors. These were computed using the R packages '*ez'* (Lawrence, 2016), '*WRS2'* (Wilcox & Schönbrodt, 2014), and '*BayesFactor'* (Morey & Rouder, 2015), respectively.

4.1.7.1 Alpha band oscillations

The data regarding the alpha band power for own stimuli and a low task load are summarised in *Figure 20* and *Table 19*. Mean alpha power data were submitted to a 2x2 repeated-measures-ANOVA with ContraIpsi (Contralateral vs. Ipsilateral) and Sharing (Shared vs. Notshared) as within-subjects factors (see *Figure 20*). The ANOVA revealed a significant main effect of ContraIpsi, F(1, 30) = 33.10, p = 2.78e-6, η_G^2 =0.048, due to the typically larger alpha suppression at contralateral sites ($M_{contralateral}$ = -1.13 dB, 95% CI [-1.78, -0.48]), relative to ipsilateral ones ($M_{ipsilateral}$ = -0.36 dB, 95% CI [-0.92, 0.20]). The main effect of Sharing was not significant, F(1, 30) = 0.51, p = .482, nor the ContraIpsi x Sharing interaction, F(1, 30) = 0.01, p = .934.

The percentile bootstrap method on 20% trimmed means mirrored the ANOVA results by yielding a significant main effect of ContraIpsi, $\hat{\psi}$ = -1.55 [-2.10, -0.98], *p* = 0, a non-significant main effect of Sharing, $\hat{\psi}$ = 0.20 [-0.45, 0.86], *p* =.563, and a non-significant interaction ContraIpsi x Sharing, $\hat{\psi}$ = 0.10 [-0.29, 0.49], *p* =.610. Bayes factors for this interaction (*BF10* = 0.262) suggested "moderate" support for the model without the interaction, given the data.

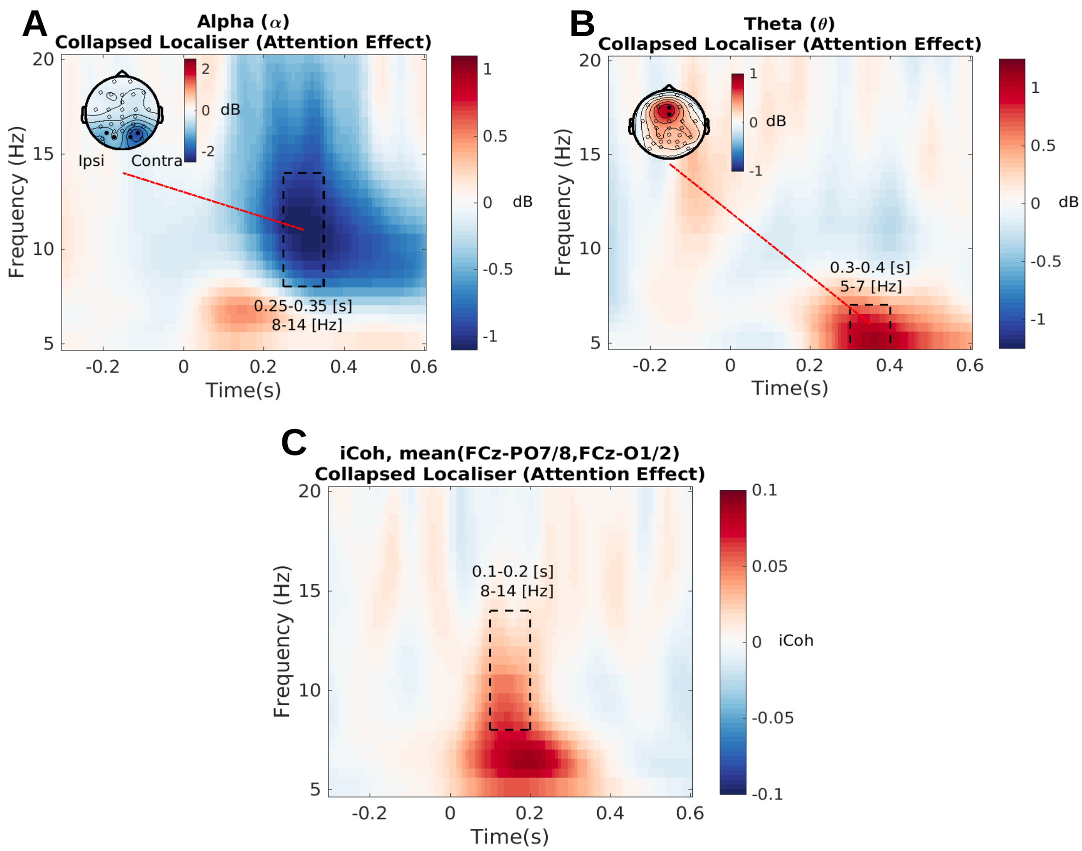


Figure 19. Collapsed localisers for TFRs. Collapsed localisers were employed to determine the electrode sites and time-windows of interest for the posterior alpha and mid-frontal theta power. **A) Alpha power**. Parieto-occipital sites (PO7/8, O1/2) contralateral and ipsilateral to the attended stimulus location, in the time window [250-350*ms*], were considered for the subsequent analysis on the non-collapsed data. **B)**

Theta power. Fronto-central sites (Fz, FCz) in the time window [300-400ms] were considered for statistical analysis on the non-collapsed data. **C) Alpha band imaginary coherence.** The sites of interest were chosen based on the relevant channels for the alpha and theta power analysis (FCz-PO7/8, FCz-O1/2). Based on collapsed localisers, the time window [100-200ms] was considered for the subsequent analysis.

4.1.7.2 Alpha band connectivity

The data regarding the alpha band connectivity (imaginary coherence) for own stimuli and a low task load are summarised in *Figure 21* and *Table 20*. Mean imaginary coherence data were submitted to a 2x2 repeated-measures-ANOVA with ContraIpsi (Contralateral vs. Ipsilateral) and Sharing (Attention Shared vs. Notshared) as within-subjects factors (see *Figure 21*). In this case, the ContraIpsi factor represents the connectivity between prefrontal (FCz) and posterior (PO7/8, O1/2) areas either contralateral or ipsilateral to the attended stimulus location. The ANOVA yielded a significant main effect of ContraIpsi, F(1, 30) = 7.84, p = .009, η_G^2 =0.022, due to a stronger connectivity in the alpha band between prefrontal (FCz) and parieto-occipital sites (PO7/8, O1/2) contralateral to the attended stimuli ($M_{FCz\text{-}Contralateral}$ = 0.08 iCoh, 95% CI [0.05, 0.12]) compared to ipsilateral sites ($M_{FCz\text{-}Ipsilateral}$ = 0.05 iCoh, 95% CI [0.01, 0.08]). The interaction ContraIpsi x Sharing was also significant, F(1, 30) = 4.57, p = .041, η_G^2 =0.010, indicating a modulation of the attention effect across attention sharing conditions. The attention effect was defined in this case as the difference in the connectivity between prefrontal and posterior contralateral sites and the connectivity between prefrontal and posterior ipsilateral sites (i.e., $M_{AttEffect} = M_{FCz\text{-}Contralateral} - M_{FCz\text{-}Ipsilateral}$). This difference was stronger when the dyad shared the attended locations ($M_{AttEffect, Shared}$ = 0.06 iCoh, 95% CI [0.02, 0.09]), than when their locus of attention differed ($M_{AttEffect, NotShared}$ = 0.01 iCoh, 95% CI [-0.02, 0.04]). The main effect of Sharing was not significant, F(1, 30) = 1.02, p = .321.

In line with the ANOVA results, the percentile bootstrap method on 20% trimmed means yielded a significant main effect of ContraIpsi, $\hat{\psi}$ = 0.06 [0.02, 0.10], *p* = .004, a non-significant main effect of Sharing, $\hat{\psi}$ = 0.03 [-0.06, 0.12], *p* =.474, and a significant interaction ContraIpsi x Sharing, $\hat{\psi}$ = -0.04 [-0.08, -0.001], *p* =.048. Bayes factors for this interaction (*BF10* = 0.437) remained insensitive.

Post-hoc simple main effects analysis examined the effect of Sharing separately for the each of the ContraIpsi conditions. Both the classic ANOVA and the (robust) percentile bootstrap on 20% trimmed means yielded a non-significant difference in the imaginary coherence values between prefrontal and posterior contralateral sites across Sharing conditions, *F*(1, 30) = 0.03, *p* = .864; $\hat{\psi}$ = 0.01 [-0.04, 0.05], *p* = .819. Similarly, no statistical difference was obtained when comparing the imaginary coherence values between prefrontal and posterior ipsilateral sites across Sharing conditions, *F*(1, 30) = 3.46 , *p* = .072; $\hat{\psi}$ = 0.03 [-0.01, 0.09], *p* = .164.

4.1.7.3 Theta band oscillations

The data regarding the theta band power for own stimuli and a low task load are summarised in *Figure 22* and *Table 21*. Mean theta band power data were submitted to a 2x2 repeated-measures-ANOVA with Attention (Attended vs. Unattended) and Sharing (Shared vs. Notshared) as within-subjects factors (see *Figure 22*). The ANOVA revealed a significant main effect of Attention, F(1, 30) = 21.32, p = 6.86e-5, η_G^2 =0.080, due to a typical attention effect as measured in the alpha power relative to the baseline period. That is, a greater Theta activity was obtained for Attended stimuli ($M_{attended}$ = 1.72 dB, 95% CI [1.29, 2.15]) than for Unattended ones ($M_{unattended}$ = 1.02 dB, 95% CI [0.68, 1.35]). The interaction Attention x Sharing was also significant, F(1, 30) = 5.18, p = .030, η_G^2 =0.013, due to a larger attention effect (i.e., $M_{AttEffect}$ = $M_{attended}$ – $M_{unattended}$) when the dyad shared the attended locations ($M_{AttEffect, Shared}$ = 0.97 dB , 95% CI [0.62, 1.32]), than when their locus of attention differed ($M_{AttEffect, NotShared}$ = 0.43 dB, 95% CI [0, 0.86]). The main effect of Sharing was not significant, F(1, 30) = 1.68, p = .205.

The percentile bootstrap method on 20% trimmed means echoed the ANOVA results, showing a significant main effect of Attention, $\hat{\psi}$ = 1.15 [0.69, 1.67], *p* = 0, a non-significant main effect of Sharing, $\hat{\psi}$ = 0.16 [-0.46, 0.91], *p* =.667, and a significant interaction Attention x Sharing, $\hat{\psi}$ = -0.62 [-1.10, -0.10], *p* =.022. Bayes factors for this interaction (*BF10* = 0.504) remained insensitive.

Post-hoc simple main effects analysis examined the effect of Sharing separately for the each of the Attention conditions. The mean theta power to attended locations was not statistically different across sharing conditions, $F(1, 30) = 0.04$, $p = .835$ (ANOVA); $\hat{\psi}$ = -0.06 [-0.48, 0.28], $p = .721$ (percentile bootstrap on 20% trimmed means). In addition, the ANOVA revealed that the mean theta power to unattended locations was significantly smaller when dyads shared the locus of attention in the task, than when this locus was not shared (see *Table 21*), $F(1, 30) = 5.48$, $p = .026$, η^2_G = 0.05, but this result was not supported by the robust test, $\hat{\psi}$ = 0.33 [-0.07, 0.86], p = .115.

4.1.7.4 Correlation analysis: N2b component ~ Theta band power

It has been suggested that the N2b component and the mid-frontal theta power may represent different mechanisms or different aspects of control processes (Cohen, 2018; Cohen & Donner, 2013), and it has been shown that they are typically not correlated (Cohen & Donner, 2013). This was examined in the current data. Spearman’s correlation confirmed this notion, revealing a non-significant correlation between them, $r_s = -0.037$, $p = .857$.

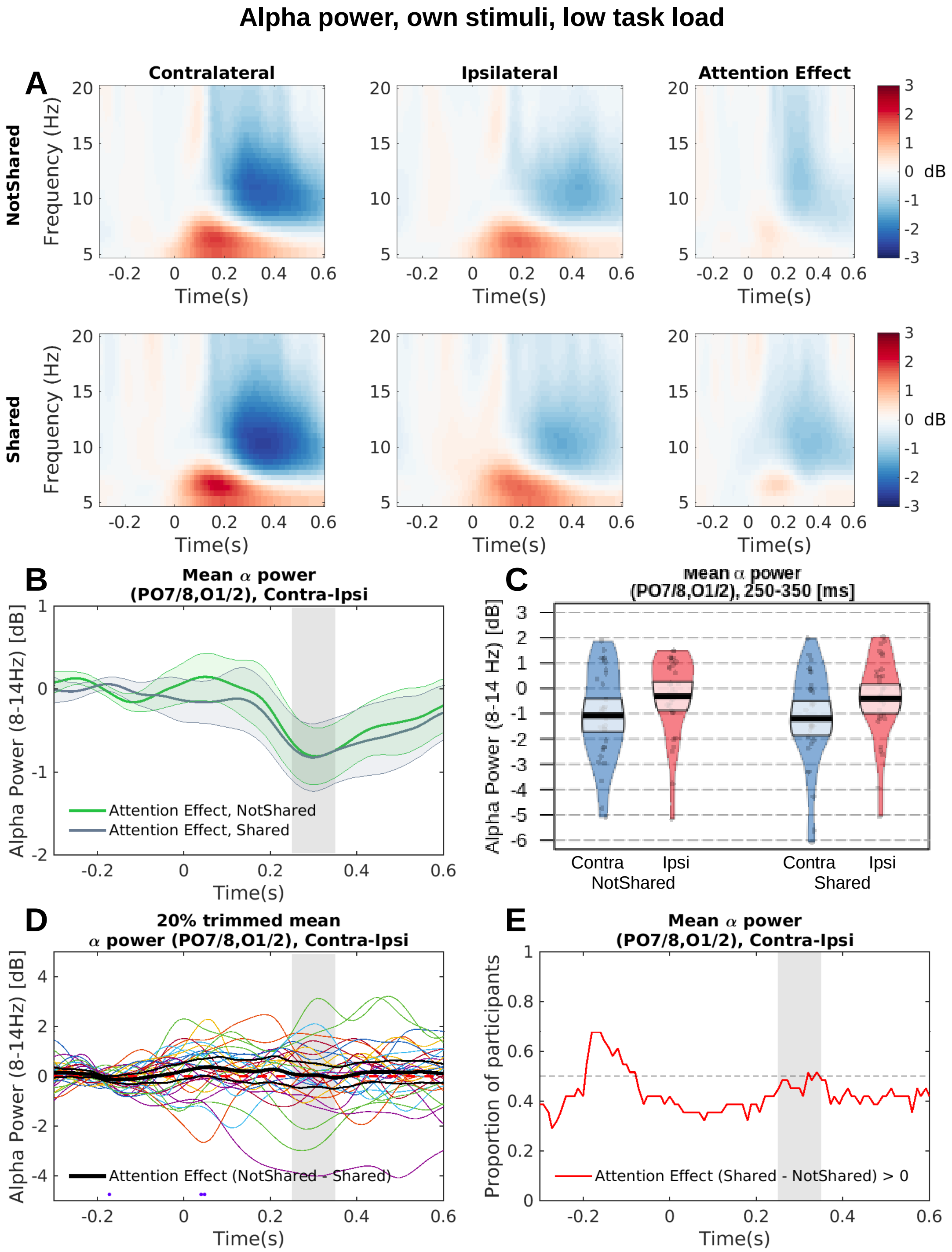


Figure 20. Alpha power. A) Grand-average time-frequency representations of power relative [*dB*] to the baseline period [-0.3 to -0.1s] were calculated at parieto-occipital sites (PO7/8, O1/2), contralateral and ipsilateral to the attended stimulus location. The attention effect here is defined as the power difference between contralateral and ipsilateral sites (i.e., power contralateral – power ipsilateral). **B)** Attention effect across attention sharing conditions (i.e., attention Shared vs. Notshared). The shaded areas surrounding the waveforms represent 95% CIs. The time-window of interest [250-350*ms*] is displayed in grey. **C)** Pirateplot showing the mean alpha power for the time window of interest [250-350*ms*]. The grey boxes surrounding the mean values

represent 95% CIs. **E)** 20% trimmed mean difference between the attention effect for the attention Notshared and Shared conditions. This difference is displayed with 95% CIs around the trimmed mean. The coloured waveforms show the difference (i.e., attention effect Notshared minus Shared) for each single participant. The dashed red line represents the zero [*dB*] value. The blue dots at the bottom of the plot (below the plot legend) show the time points where a significant difference (between the attention effect for the Shared vs. Notshared conditions) was obtained using yuen's tests (for dependent groups) on 20% trimmed means (at α=0.05). These values are uncorrected for multiple comparisons. The yuen's tests were computed using the function "*limo_yuend_ttest*", part of the LIMO toolbox (Pernet, Chauveau, Gaspar, & Rousselet, 2011). **F)** Proportion of participants (from 0 to 1, for every time point) showing a stronger attention effect for the attention Shared condition, compared to the Notshared scenario. The plots B, D, and E were created using a modified version of the code available at: https://github.com/GRousselet/blog/tree/master/erp_differences

Table 19. Mean alpha power in dB (with SD), at parieto-occipital sites (PO7/8, O1/2), contralateral and ipsilateral to the attended stimulus location, in the time window [250-350ms].

Experimental Condition			
Notshared		Shared	
Contralateral	Ipsilateral	Contralateral	Ipsilateral
-1.07(1.81)	-0.31(1.60)	-1.19(1.91)	-0.41(1.64)

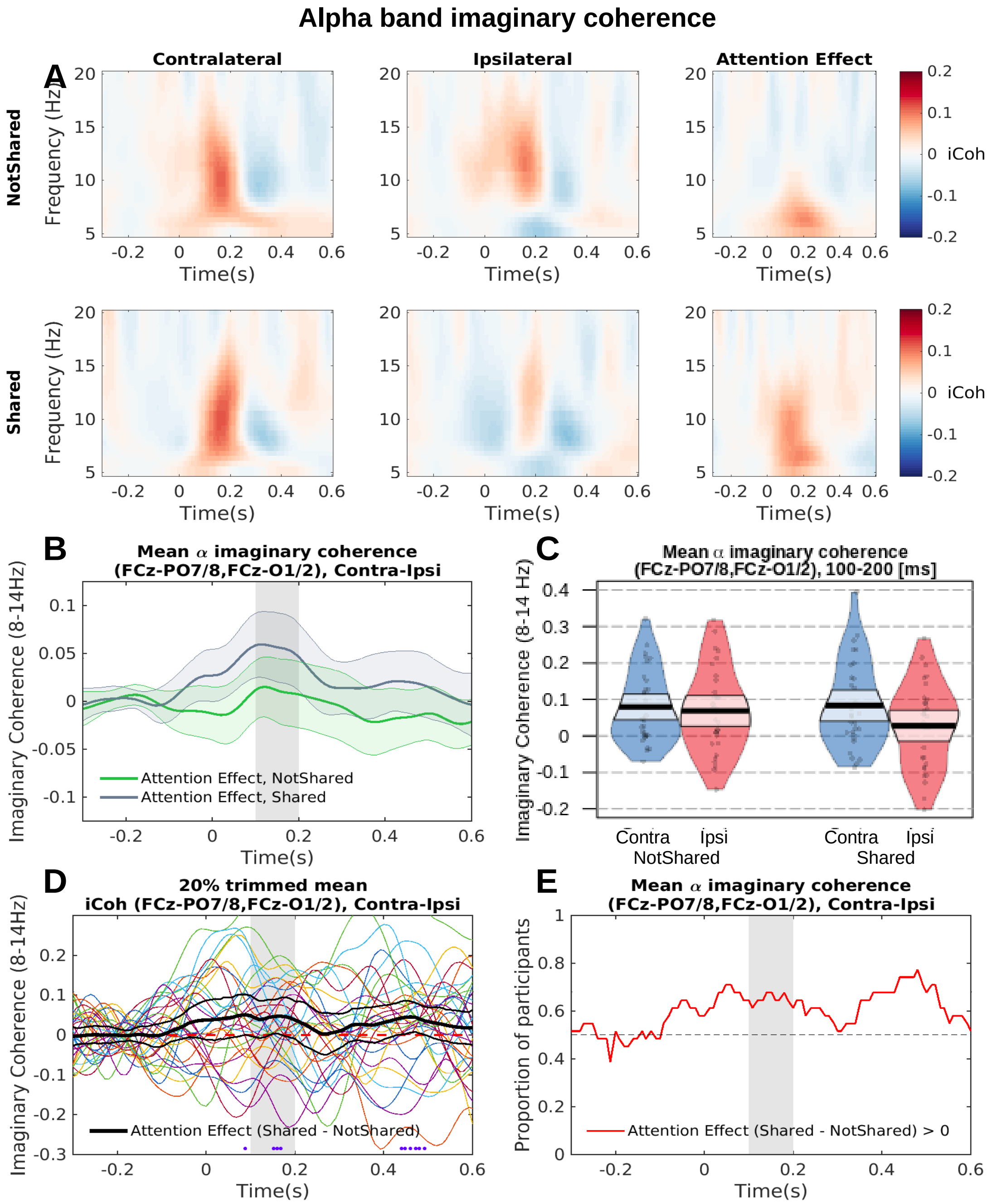


Figure 21. Alpha band connectivity (imaginary coherence values) between prefrontal and parieto-occipital sites. A) Grand-average time-frequency representations showing alpha band imaginary coherence values between pre-frontal (Fz, FCz) and parieto-occipital sites (PO7/8, O1/2 contra and ipsilateral to the attended stimulus location). These values are baseline corrected to the period [-0.3 to -0.1s]. The attention effect here is defined as the difference in the connectivity values between pre-frontal and contralateral vs. ipsilateral sites. **B)** Attention effect across attention sharing conditions (i.e., attention Shared vs. Notshared). The shaded areas surrounding the waveforms represent 95% CIs. The time-window of interest [100-200*ms*] is displayed in grey. **C)** Pirateplot showing the mean alpha band imaginary coherence values for the time window of interest [100-200*ms*]. The grey boxes surrounding the mean values

represent 95% CIs. **E)** 20% trimmed mean difference between the attention effect for the attention Shared and Notshared conditions. This difference is displayed with 95% CIs around the trimmed mean. The coloured waveforms show the difference (i.e., attention effect Shared minus Notshared) for each single participant. The dashed red line represents the zero [*iCoh*] value. The blue dots at the bottom of the plot (below the plot legend) show the time points where a significant difference (between the attention effect for the Shared vs. Notshared conditions) was obtained using yuen's tests (for dependent groups) on 20% trimmed means (at α =0.05). These values are uncorrected for multiple comparisons. The yuen's tests were computed using the function "*limo_yuend_ttest*", part of the LIMO toolbox (Pernet, Chauveau, Gaspar, & Rousselet, 2011). **F)** Proportion of participants (from 0 to 1, for every time point) showing a stronger attention effect for the attention Shared condition, compared to the Notshared scenario. The plots B, D, and E were created using a modified version of the code available at: https://github.com/GRousselet/blog/tree/master/erp_differences

Table 20. Mean alpha band imaginary coherence values (with SD) between pre-frontal (Fz, FCz) and parieto-occipital sites (PO7/8, O1/2 contra and ipsilateral to the attended stimulus location), in the time window [100-200ms].

Experimental Condition			
Notshared		**Shared**	
Contralateral	**Ipsilateral**	**Contralateral**	**Ipsilateral**
0.08(0.10)	0.07(0.12)	0.08(0.12)	0.03(0.12)

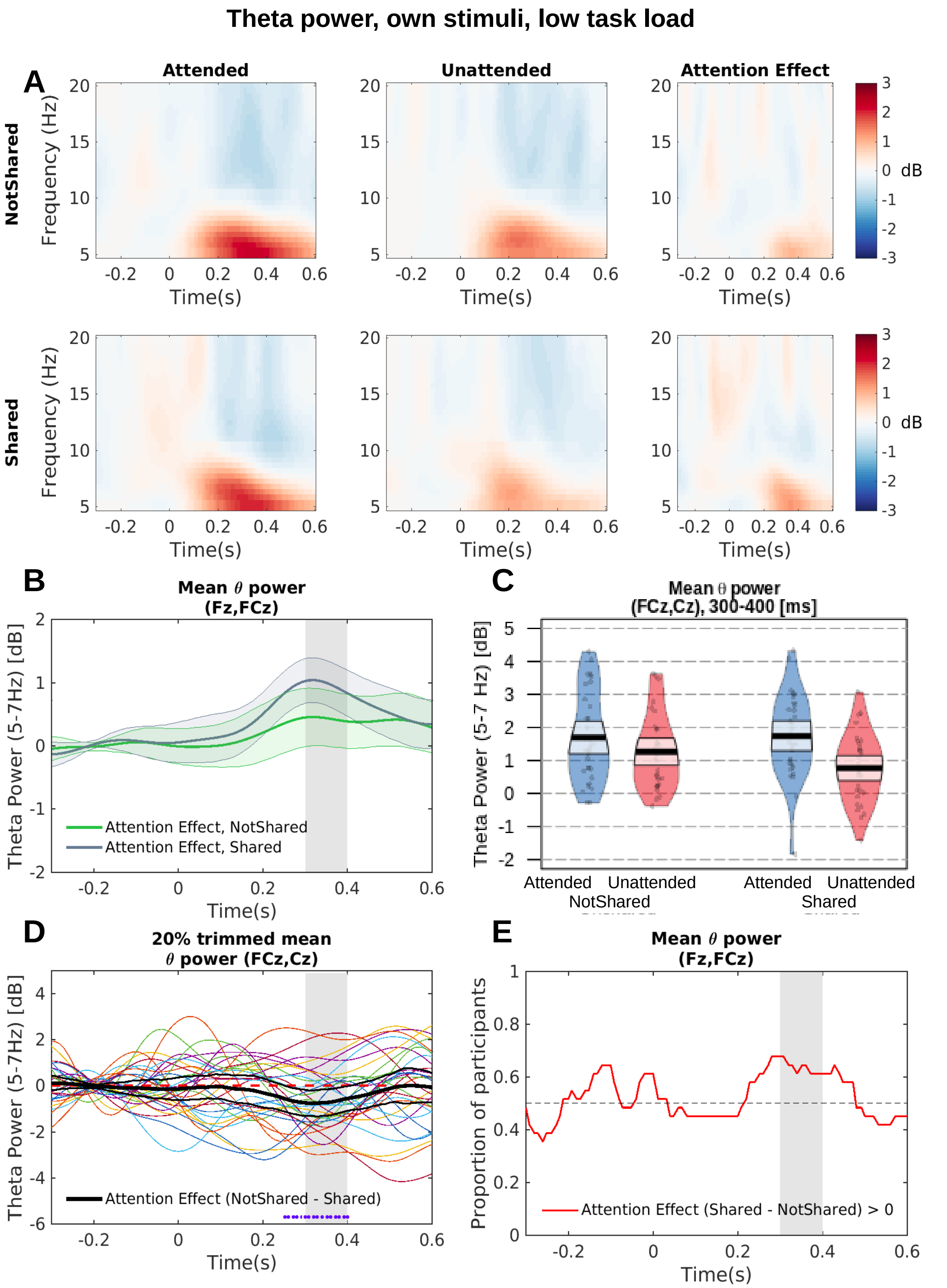


Figure 22. Theta power. A) Grand-average time-frequency representations of power relative [*dB*] to the baseline period [-0.3 to -0.1s] were calculated at fronto-central sites (Fz, FCz). The attention effect here is defined as the power difference between attended and unattended conditions (i.e., attended – unattended). **B)** Attention effect across attention sharing conditions (i.e., attention Shared vs. Notshared). The shaded areas surrounding the waveforms represent 95% CIs. The time-window of interest [300-400*ms*] is displayed in grey. **C)** Pirateplot showing the mean alpha power for the

time window of interest [300-400*ms*]. The grey boxes surrounding the mean values represent 95% CIs. **E)** 20% trimmed mean difference between the attention effect for the attention Notshared and Shared conditions. This difference is displayed with 95% CIs around the trimmed mean. The coloured waveforms show the difference (i.e., attention effect Notshared minus Shared) for each single participant. The dashed red line represents the zero [*dB*] value. The blue dots at the bottom of the plot (below the plot legend) show the time points where a significant difference (between the attention effect for the Shared vs. Notshared conditions) was obtained using yuen's tests (for dependent groups) on 20% trimmed means (at α=0.05). These values are uncorrected for multiple comparisons. The yuen's tests were computed using the function "*limo_yuend_ttest*", part of the LIMO toolbox (Pernet, Chauveau, Gaspar, & Rousselet, 2011). **F)** Proportion of participants (from 0 to 1, for every time point) showing a stronger attention effect for the attention Shared condition, compared to the Notshared scenario. The plots B, D, and E were created using a modified version of the code available at: https://github.com/GRousselet/blog/tree/master/erp_differences

Table 21. Mean theta power in dB (with SD), at fronto-central sites (Fz, FCz), in the time window [300-400ms].

Experimental Condition			
Notshared		**Shared**	
Attended	**Unattended**	**Attended**	**Unattended**
1.69(1.35)	1.22(1.13)	1.74(1.26)	0.77(1.04)

4.1.8 Discussion

The current chapter investigated the neural correlates of the dual attention effect (i.e., the attention performance drop observed when participants share the locus of attention in the dual attention task). Specifically, the chapter examined the information processing stage(s) influenced by dual attention, and asked whether the dual attention effect, takes place at a sensory-level vs. a cognitive control stage. Both event-related potentials and neural oscillations pointed towards the later, as suggested by a stronger engagement of cognitive control (in the attention effects associated with the N2b component and theta band oscillations) when the dyad shared the attended spatial locations during the task. This inhibitory higher-order process however, is preceded by an enhanced early sensory attention effect for the same condition (measured in the P1 event-related component). These findings suggest that dual attention differently affects these two information processing stages in the brain, but is potentially driven by a cognitive control process.

4.1.8.1 N2b component and theta oscillations

Dual attention modulated the information processing stage related to cognitive control. The N2b component showed a reduced attention effect when attention was shared than notshared by the dyad while completing the dual attention task, a result that mirrors the behavioural attention performance reduction presented in Chapter 2. Analogue to this, a stronger mid-frontal theta band power attention effect was obtained when the dyad shared the locus of attention, relative to attention notshared condition. Taken together these results suggest a stronger need for control when sharing the attended spatial locations with another person in the dual attention task. Although both mid-frontal theta power and the N2b component are known to be neural markers of cognitive control, it has been suggested that they may reflect different aspects of control processes (e.g., Cohen, 2018; Cohen & Donner, 2013). Indeed, these two neural responses are typically not correlated, which is also the case in the current data. Moreover, even though mid-frontal theta has been shown to correlate better with behaviour and to have a higher statistical power than the N2b component (Cohen, 2014b; Cohen & Donner, 2013), the functional significance of these oscillations and the way they may aid the implementation of control is still unknown (Cohen, 2014b, 2018; Cohen & Donner, 2013). It is beyond the scope of the current Chapter (and thesis) to contribute to this debate. The relevance of the current data lies in providing evidence for a variable need for control depending on whether one shares or not the locus of attention with another person in the dual attention task (with a stronger involvement of control processes when this locus is shared).

Chapter 2 introduced some potential (higher-order processing) accounts for the dual attention effect. It was argued that perhaps the knowledge of being sharing the attended spatial location with another person could elicit extra higher order processing like mentalising, or monitoring the other’s (or one’s) task (or task performance). This would implicate deploying additional resources to a secondary task (like mentalising/monitoring), which could explain the behavioural attention performance reduction characterising the dual attention effect. It was also proposed that the task partner could feel more threatening or evaluative when sharing one’s locus of attention, which could induce an executive attention drop (see Belletier, Normand, & Huguet, 2019). Moreover, it was considered that perhaps due to co-representation of the partner’s targets (and considering the statistical properties of these target stimuli in the task), a stronger response inhibition could be needed for the attention shared vs. notshared condition. All these higher order processes potentially explaining the dual attention effect could be linked to the current EEG findings in relation to the N2b component and theta band oscillations. It is important to clarify that the present data cannot discriminate among these accounts, discarding or supporting a specific one. Nonetheless, the following paragraphs will discuss their potential link to the data and propose some future directions.

Both frontal theta oscillations and the N2b component have been shown to be originated in the mPFC, particularly in the ACC (Cavanagh & Frank, 2014; Crottaz-Herbette & Menon, 2006; Ishii et al., 2014; Van Veen & Carter, 2002). The ACC is implicated in a wide range of cognitive processes (Van Veen & Carter, 2002; Vassena, Holroyd, & Alexander, 2017), including the processing of social information (Apps, Balsters, & Ramnani, 2012; Apps, Lockwood, & Balsters, 2013; Apps & Ramnani, 2014; Apps, Rushworth, & Chang, 2016). From the purely cognitive side, response selection and inhibition, reward processing, conflict and performance monitoring, and error prediction and detection, are some of the processes associated to ACC activations (see Alexander, Vassena, Deraeve, & Langford, 2017; Vassena et al., 2017 for relevant reviews). At the more social side of the spectrum, the ACC is activated when mentalising is required (Gallagher et al., 2000; Ruby & Decety, 2001; Van Overwalle, 2009), and plays an active role in monitoring others (Apps, Rushworth, & Chang, 2016; see below for further details). In addition, it has been shown that joint attention (as compared to dis-joint attention) more strongly activates brain networks related to both mentalising (Williams, Waiter, Perra, Perrett, & Whiten, 2005) and processing rewards (Gordon et al., 2013; Pfeiffer et al., 2014; Schilbach et al., 2010). Following the latter, it has been proposed that joint attention is a socially more rewarding experience than disjoint attention (Gordon et al., 2013). This idea could be investigated in future studies in relation to dual attention (e.g., examining whether manipulating rewards modulates the dual attention effect and the ACC response).

It has been shown that the ACC of primates contains cells sensitive to social context, able to monitor and predict the behaviour and state of mind of other conspecifics (Haroush & Williams, 2015). In the ACC of humans, this role has been tracked down to the gyral section of the cingulate cortex (aka., anterior cingulate gyrus or ACCg) (see Apps, Rushworth, & Chang, 2016 for a review). The ACCg is known to process social information and seems to play a key role in processing, monitoring and predicting other's mental states (Apps, Balsters, & Ramnani, 2012; Apps, Lockwood, & Balsters, 2013; Apps & Ramnani, 2014; Apps, Rushworth, & Chang, 2016). Indeed, it has been suggested that this area processes information in an "other-oriented" reference frame, responding to "other-oriented" information but not to information relevant to the self (Apps, Rushworth, & Chang, 2016). On the other hand, a similar role has been attributed to the anterior cingulate sulcus (aka., ACCs or ACCd - for dorsal ACC) in relation to self relevant information (Apps, Rushworth, & Chang, 2016). Future experiments could address the potential roles of the ACCg and the ACCs in relation to the dual attention effect, and their interaction to the attention and control networks in the brain. In addition, multimodal imaging (e.g., fMRI-EEG, or MEG informed by structural MRI) could investigate whether the theta band oscillations here reported are generated in (or related to) these specific areas.

Chapter 2 argued for response inhibition as one of the potential accounts for the dual attention effect. On the one hand, it was argued that due to co-representation of the (task) partner's stimuli, the partner's targets could prime one's own target-relevant response, with a subsequent need to inhibit this primed response given one's instructions set. Given the unbalanced distribution of target stimuli in the task (see Chapter 2 for a detailed explanation of the distribution of stimuli in the task), this need to inhibit a primed response may be stronger for the attended-shared condition. Here however, the distribution of target stimuli was matched across attention sharing conditions, yet, a dual attention effect in N2b (and the related modulation in mid-frontal theta power) was obtained. Following the argument above, no dual attention effect should be obtained with a balanced distribution of target stimuli in the task. Therefore, under the evidence here presented, it seems less plausible to explain the dual attention results as merely elicited by a mixture of target co-representation and the related response priming/inhibition. Nonetheless, response priming/inhibition could still account for the current findings if examined in line with previous evidence regarding evaluative pressure and its influence on selective attention distractability (Normand, Bouquet, & Croizet, 2014; see also Belletier, Normand, & Huguet, 2019). Normand et al. (2014) showed that evaluative pressure increases distractability by an irrelevant stimulus if the features of the irrelevant stimulus are contingent to the task set (they also showed that distractability was reduced when the stimulus did not share the set features, but this is less relevant). The authors went further by showing that this interference occurs at the response selection stage, with the increased distraction deriving from a greater visuomotor priming from the irrelevant (but contingent) stimulus (Normand et al., 2014). In the context of the dual attention task, a task partner deploying covert attention towards the same spatial location one is focusing on could feel more threatening or could imply a higher evaluative potential than a partner attending to a different location. Following Normand and colleagues' findings, perhaps the (potentially) higher evaluative pressure for the attention shared condition could also lead to higher distractability due to contingent interference at the response selection stage. In this case, the contingent interference would arise from the task partner's targets (i.e., from stimuli sharing a key feature of one's task set -the stimulus size), leading to an enhanced response priming that needs to be inhibited. Both evaluative threat processing and response inhibition have been linked to activity in the prefrontal cortex (including the ACC) (Alexander et al., 2017; Vassena et al., 2017), and both modulate the N2b amplitudes and theta power (Alexander et al., 2017; Andreu et al., 2019; Dennis & Chen, 2009; Funderud et al., 2012; Harrewijn et al., 2018; Kamarajan et al., 2004). Therefore, the current EEG data cannot distinguish among them or disentangle their potential relation to the present results. Additional experiments should address this issue. For instance, an fMRI study investigating the effective connectivity among the specific areas related to monitoring evaluative threats, and response selection/inhibition could shed some light on their roles in dual attention. In terms of EEG, it has been suggested that different theta sub-bands may be individually related to stimulus and response codes in inhibitory control, with stimulus codes linked to upper theta (~7Hz), and response codes to lower theta oscillations (~4Hz) (Mückschel et al., 2017). The role of specific frequencies within the theta range was not examined here due to limitations in the current experimental design (this discussion is expanded in Chapter 5). Further research could investigate these sub-bands in relation to dual attention.

Importantly, this is not the first time that modulations in theta oscillations were found to be associated with social attention. A similar result was obtained by Wass et al. (2018) while examining infants-caregivers dynamic exchanges in naturalistic settings. In Wass et al., infant-caregivers dyads had their eye movements monitored and their EEG activity simultaneously recorded while playing with an object either together or alone. Interestingly, in this naturalistic scenario, the caregivers EEG theta power tracked the infants' attention. The adults' theta power increased after infants looked to the object in the joint condition, and the longer the infants sustained attention towards the object, the stronger the caregivers' theta power was (Wass et al., 2018).

Their results suggested that the caregivers' theta power backwards-predicted (not forward-predicted) the length of the infants overt attention deployment towards the object, implying that the adult's theta oscillations responded to the infant's attention adjustments (Hoehl & Markova, 2018; Wass et al., 2018). However, the authors also showed that this increase in the adult's theta power was still present after excluding all those cases in which an attention shift from the infant was followed by an attention shift from the adults, suggesting that this finding could not simply be explained by the infants gaze shifts Granger-causing the adults attention changes and the subsequent theta enhancement (i.e., the information contained in the infants signal did not help in the prediction of the adults' results beyond the prediction that could be made from the adults information alone; see Granger, 1969). No alternative account was proposed by Wass and colleagues (their study focused on the babies' neural responses, and the adult's findings were a secondary outcome). Perhaps, considering together the results obtained by Wass et al. (2018) and the dual attention findings here reported, one could speculate that the increase in theta power is not directly related to gaze following (this argument will be expanded below when discussing the alpha band oscillations results), but to higher order processing induced by the knowledge of being simultaneously attending to the same locations with another person. Future research should examine if this is indeed the case.

4.1.8.2 P1 component and alpha band oscillations

The P1 component showed an enhanced attention performance at the sensory level (a stronger attention effect) when attention was shared by the dyad while completing the dual attention task, relative to attention notshared condition. This finding echoes the results presented in Experiment 2 (in Chapter 2). As a reminder, Experiment 2 (i.e., the solo version of the dual attention task) was carried out to investigate whether the dual attention effect was merely driven by the unbalanced distribution of target shapes in the dual attention task. That is, although the overall stimulus distribution was balanced in the original paradigm, to encourage the instructed attention shifts, 75% of the target shapes were displayed at the attended location for each participant. Therefore, for the attention shared condition 75% of the targets for both participants appeared at the same spatial location, while for the notshared condition one location displayed 75% of the targets for one participant and the alternative location showed 75% of the targets for the remaining participant. Under these settings, participants showed a larger attention effect for the "shared condition" than for the “notshared” one. This was discussed as a likely sensory driven attention effect enhancement for the shared condition, potentially induced by the statistical properties of the stimuli in the task (see Chapter 2). Although Experiment 2 and the P1 component analysis in the current chapter showed a similar pattern, the stimulus distribution, deemed as the factor driving the result in Exp2, was modified in the current experiment. Here, the overall stimulus distribution, including the distribution of target stimuli, were balanced across attention sharing conditions (see the methods section in the current chapter). Following the reasoning employed in Experiment 2, a balanced target distribution (i.e., 50% target probability for any condition) would probably lead to equivalent attention effect for both “shared” and “notshared” conditions in a hypothetical solo version of the task. Thus, a purely stimulus driven account (i.e., non social but linked to the stimulus distribution in the task) of the P1 component related findings in the present experiment seems unlikely.

Considering that all the aspects of the current task were matched across attention sharing conditions, it is plausible to consider that the changes in P1 were related to the social context of the task. In this line, the present results also echo the joint Navon (task) findings by Böckler and Sebanz (2012). They showed that co-representing a co-actor’s focus of attention in the joint Navon modulates the early attentional processes reflected by P1. P1 amplitudes were reduced when the co-actor had a different versus the same focus of attention (i.e., local vs. global features) (Böckler & Sebanz, 2012b). The authors suggested this could be explained by an increased difficulty in selecting one’s focus of attention when the co-actor’s one differs. Thus, it could be plausible to consider that a potential co-representation of the task-partner’s attentional locus in the dual attention task could have interfered with one’s attention, at least at the early stage of information processing related to P1. However, although this narrative sounds reasonable in relation to the P1 results, it may not explain the dual attention effect. This argument would suggest an attention performance reduction when the dyad’s locus of attention differs, which is the exact opposite to the pattern obtained in the previous experiments. Additional experiments are needed to shed more light regarding the influence of dual attention on this early stage of information processing in the brain.

As typically reported in the visual attention literature (e.g., Sauseng et al., 2005), the current data showed a larger alpha band power suppression at contralateral compared to ipsilateral posterior sites. This alpha reduction however, was not modulated by the social context of the task. In other words, the attention effect in visual alpha oscillations remained unchanged across attention sharing conditions. Importantly, the present experiment is not the first in reporting joint attention related variations in theta band power while the alpha band power remained unaffected. A similar pattern was obtained by Wass et al. (2018) in their study on naturalistic infant-caregiver interactions (described above). Interestingly, for the adults taking part in Wass et al. (2018), EEG power variations in the alpha band were related to visual attentional changes when performing in isolation (solo play condition), but this association shifted to the theta band when interacting with the babies in the joint condition (Wass et al., 2018).

However, other studies in the joint attention literature have provided evidence for alpha band power modulations when comparing joint versus dis-joint attention conditions (e.g., Hoehl et al., 2014; Lachat et al., 2012; Michel et al., 2015; Rayson et al., 2019). For instance, research with infants has shown a greater suppression of alpha band activity when an adult (a picture of an adult's face) turned her gaze towards the attended object than when her gaze looked towards a different object (Rayson et al., 2019), or when looking to an object attended by another person compared to an averted gaze (i.e., they used a picture of a person gazing towards an object in the screen or averting gaze from the object) (Michel et al., 2015). Similarly, in Hoehl et al. (2014) babies showed a widespread alpha reduction when looking at the same object in the screen simultaneously with an adult (this time a real one) positioned next to the screen, but only when eye contact with the adult preceded joint attention. In adults, Lachat et al. (2012) also obtained a stronger alpha reduction for joint vs. dis-joint attention. In this case, two people sat face-to-face and moved their eyes towards LED targets (displayed in between the two participants) either jointly or dis-jointly. Although a real person (the task partner) was present, the dynamic was equivalent to the typical gaze-cueing paradigms (e.g., Friesen & Kingstone, 1998) (but replacing the traditional picture in the screen by the real person). Indeed, these paradigms showing changes in alpha oscillation linked to joint attention (Hoehl et al., 2014; Lachat et al., 2012; Michel et al., 2015; Rayson et al., 2019) have used gaze-cueing-like paradigms where eye contact and gaze following play an essential role.

On the other hand, in the dual attention paradigm participants are simply instructed to hold their fixation to the screen centre while deploying covert attention towards one side of the screen. They have no visual access to their partner's face or gaze-behaviour, and gaze-following is not implicated. Similarly, in Wass et al. (2018) attentional shifts were separately monitored (for the babies and the caregivers while playing with an object) as attention episodes towards the common object (and inattention episodes), and were later related to their EEG activity. Eye contact or strict gaze-following episodes were not directly monitored in the task and therefore it is unclear how relevant they were in the actual infant-caregiver interaction and in the related measurements. Wass and colleagues considered that the infants gaze shifts Granger-causing the adults attention changes and the subsequent theta enhancement could account for their findings. However, they subsequently pushed aside this argument based on additional analysis. First, they excluded all those cases in which an attention shift from the infant was followed by an attention shift from the adults, and yet, they got the same increased theta power in the caregivers as a response to the infants attentional changes (Wass et al., 2018). In addition, their results suggested that the adult's attention shifts forward-predicted the infant's shifts (more than the opposite) (Wass et al., 2018). The evidence just discussed seems to relate alpha band power changes to contexts where eye contact and gaze following play a fundamental role, while mid-frontal theta oscillations do not seem to be directly linked to these. Perhaps, the increase in theta power is not directly related to gaze following, but to higher order processing induced by the knowledge of being simultaneously attending to the same locations with another person. Perhaps alpha band modulations in joint attention are related to the reflexive nature of the gaze-cuing paradigms typically employed (Driver et al., 1999; Friesen & Kingstone, 1998; Langton, Watt, & Bruce, 2000; Xu, Zhang, & Geng, 2011)? Future research should address these thought provocative ideas.

4.1.8.3 Alpha band functional connectivity

It was here hypothesised that the typical attention effect in alpha band power would be accompanied by an attention effect in terms of functional connectivity between prefrontal and posterior areas. This was corroborated in the current data using the imaginary part of coherence as the functional connectivity measure. It was also expected that the social context of the task would modulate both the attention effect in alpha power and the above-mentioned functional connectivity. Here however, although the posterior alpha power remained unchanged across attention sharing conditions, a stronger attention effect in functional connectivity (iCoh) between mid-frontal and posterior brain regions was obtained when sharing vs. not sharing the attended spatial locations in the dual attention task. This suggests a modulation in the information flow between prefrontal and posterior areas by dual attention, even in the absence of local oscillatory power changes at posterior sites. Taking into account that alpha oscillations are considered as a top-down rhythm (see Halgren et al., 2019), this flow of information may well be top-down oriented. Nonetheless, the current analysis do not allow for unidirectional conclusions in this regard. Considering that the social context of the dual attention task may have influenced the early processes measured by the P1 event-related component (see Wykowska et al., 2014, for additional evidence on top-down modulations over the early P1 sensory processes in the context of joint attention), it would not be as surprising to ponder around potential early top-down influences on sensory processing . Further research should aim at replicating this finding and address the direction of this potential information flow in the brain.

4.1.8.4 Behavioural results and correlations with EEG?

As introduced above, the experimental design here employed contains important differences respect to the behavioural dual attention experiments presented in the previous Chapters. In the present design, a 50% target validity (instead of 75%) was employed, and the participants responded exclusively to targets appearing at the attended side of the screen (in the previous experiments responses where made to both attended and unattended locations), while EEG responses to non-target stimuli were analysed. The behavioural responses to target stimuli at attended locations were here analysed, however, no evidence for an effect of Sharing was obtained in RTs. This outcome does not necessarily mean that attention performance (as measured in the previous experiments) did not vary across attention Sharing conditions. Previous experiments (e.g., Exp 1 and Exp3) showed that both attended and unattended locations could contribute to the attention performance changes deriving in the dual attention effect. Since participants here responded only to targets at attended locations, no data were available for unattended locations, and therefore, no clear measure of behavioural attentional performance could be derived (i.e., no attention effect). Moreover, since only EEG to non-target stimuli were analysed, these two datasets (RTs and EEG) could not be correlated to investigate their relationship. Future experiments should address this limitation (e.g., measuring and analysing behavioural responses to both attended/unattended targets, EEG responses to both go and nogo-trials, and correlations between behaviour and electrophysiology). Further details on the limitations of the current experimental design are presented in Chapter 5, along with relevant future directions (see the section *“5.4.9. Limitations of the present EEG design”*).

4.2. Chapter summary

The current chapter investigated the neural correlates of the dual attention effect, focusing on the information processing stage(s) influenced by dual attention. Event-related potentials and neural oscillations suggested that the effect may be driven by a cognitive control process, but able to modulate also early sensory level information processing in the brain. Both the N2b component and mid-frontal theta oscillations pointed towards a stronger need for control when sharing the attentional locus with another person in the dual attention task, while the P1 component yielded an enhancement in the attention effect for this attention sharing condition. The later may be top-down driven through alpha band long-range communication from prefrontal to posterior areas (but this needs to be followed-up in future experiments). Several potential higher-order processing related accounts were proposed for the current findings. However, the current EEG data cannot distinguish among them or disentangle their potential relation to the present results. Further research should address the relevance of these accounts for dual attention.

5

GENERAL DISCUSSION

The present PhD thesis aimed at contributing to the understanding of how interpersonal influences and social context inform and shape human visuospatial sustained attention in dyadic settings. In particular, this thesis investigated whether paying attention towards the same spatial location with another person modulates one's attention performance. In this line, the work described in the previous chapters attempted to answer the following questions:

(1) Does human visual attention act differently (i.e., attention performance is changed) when another person pays attention to the same location with us, in the absence of direct communication or explicit interactions (i.e., without gaze following/coordination or a speech exchange), just by knowing that the locus of attention is shared, even if this knowledge is irrelevant/trivial for one's task/goals/performance? (2) Which task components and/or social factors modulate this interpersonal influence? (3) What are the neural correlates characterizing this interpersonal influence over human attention in dyadic settings?

In the following discussion, first, an overview of the findings reported in the current thesis is presented, in line with the above-mentioned questions. Second, potential accounts for the interpersonal influence obtained when sharing the locus of attention with another person (i.e., the dual attention effect) are discussed and integrated with related literature. Finally, the limitations of the present work are described and some future directions are proposed.

5.1. Basic overview

In a series of three experiments (Experiments 1-3), Chapter 2 addressed the first of the questions presented above (i.e., Does human visual attention act differently when another person pays attention to the same location with us, in the absence of direct communication or explicit interactions?). Experiment 1 proposed the dual attention paradigm. In this paradigm, two participants (i.e., a dyad sat side by side next to each other in front of a computer) performed independent visuospatial sustained attention tasks while sharing or not their attentional locus (i.e., the attended spatial locations). Participants were instructed to respond to target shapes (in a size/shape discrimination task), while attending to one side of the computer screen (i.e., one visual hemifield, left or right) for a whole experimental block. As introduced above, the locus of attention in the task varied so that the dyad sustained attention either towards the same (i.e., attention shared condition) or different (i.e., attention not shared condition) visual hemifield. The instructed sustained attention deployment was encouraged by manipulating the distribution of target shapes in the task (i.e., 75% of the target shapes appeared at the attended side of the screen; but the overall probability of a stimulus appearing at any side of the screen however, was balanced across attention sharing conditions to prevent confounding the results). Considering previous findings in relation to the shared attention theory (Shteynberg, 2015, 2018), Experiment 1 hypothesised an enhanced attention performance when the dyad shared the locus of attention in the dual attention task, compared to the condition in which the locus of attention differed. Task performance was measured by the difference in RTs between attended vs. unattended conditions, a typical performance index known as the *attention effect* (Posner, 1980). Therefore, a stronger attention effect was expected for the attention shared scenario. Strikingly however, the results showed the opposite pattern. A reduced attention performance was obtained when the dyad sustained attention towards the same visual hemifield. This was termed *dual attention effect*.

Subsequently, Experiment 2 investigated the outcome of a single participant performing the exact same task in isolation (i.e., without a task partner). The main purpose of this experiment was to discard the unbalanced distribution of target shapes in the task (i.e., having most of the target shapes appearing at the shared hemifield) as the driver of the dual attention effect. In this case, the variation in the attention effect by the “attention sharing” conditions showed the complete opposite pattern than Experiment 1. The attention effect was enhanced for the “shared” condition in the solo version (i.e., in the condition where most of the large shapes were displayed at the same location), and reduced for the (actual) Shared condition in the two-person task, relative to the “not shared” situation. The effect observed in the solo version was deemed as stimulus driven, attributed to the unbalanced distribution of target shapes in the task. Moreover, given that the social context of the task (i.e., the presence of the task partner) was the only difference across experiments, Experiments 1 and 2 together provided strong evidence suggesting that the attention performance reduction in dyads sharing the locus of attention obtained in Experiment 1, was socially driven between individuals (interpersonally). In addition, Experiment 3 showed that the dual attention effect remained unaffected under an increased perceptual load, suggesting that the related behavioural attention performance reduction may not be taking place via a sensory-level attentional process, but that instead, the interfering inhibitory process (likely social, and related to the task partner) employs resources from a separate capacity, or is processed at a different stage (Handy & Mangun, 2000; Handy, Soltani, & Mangun, 2001). Moreover, considering that higher level processes are less likely to be affected by an increased perceptual load (Handy & Mangun, 2000), this result could also suggest that the dual attention effect takes place at a higher-level information processing stage in the brain. This idea was followed up in Chapter 4 employing the EEG technique (allowing a very precise investigation of the time course of the information processing occurring in the brain).

Meanwhile, Chapter 3 (Experiments 4 and 5) addressed the second question (i.e., which task components and/or social factors modulate the interpersonal influence in dual attention?) by manipulating the social/physical “closeness” among task partners in the dual attention task. In this line, Experiment 4 investigated the role of group membership (i.e., social closeness) on the *dual attention effect*. A minimal group manipulation based on subjective colour preferences was employed for this purpose. In addition, Experiment 5 examined the dual attention effect when the individuals in the dyad performed from remote locations (i.e., different rooms), instead than sitting side by side in their peripersonal space (i.e., spatial closeness). Experiment 4 replicated the dual attention effect reported in Experiment 1, and already replicated in Experiment 3. These replications built up important confidence regarding the robustness of the dual attention effect. However, the induced categorisation of the task partner as in-group or out-group, did not modulate this interpersonal effect. Moreover, the evidence obtained in Experiment 5 favoured the absence of the dual attention effect when performing the dual attention task with a spatially distant partner.

Finally, as introduced above, Chapter 4 (Experiment 6) investigated the neural correlates of the dual attention effect, focusing on the information processing stage(s) influenced by dual attention. In particular, the experiment asked whether the dual attention effect takes place at a sensory level vs. a cognitive control stage. In order to address this question, EEG was simultaneously recorded from pairs of participants while they performed the dual attention task. ERPs and brain oscillations were analysed, focusing on well-known neural markers of sensory level attentional processing (i.e., the P1 component and alpha oscillations; see Hillyard, Vogel, & Luck, 1998; Sauseng et al., 2005), and cognitive control (i.e., the N2b component and mid-frontal theta oscillations; Folstein & Van Petten, 2008; Cavanagh & Frank, 2014). These analyses suggested that the dual attention effect may be driven by a cognitive control process, but able to modulate also early sensory level information processing in the brain. Both the N2b component and mid-frontal theta oscillations pointed towards a stronger need for control when sharing the attentional locus with another person in the dual attention task, while the P1 component yielded an enhancement in the attention effect for this attention sharing condition. Moreover, functional connectivity analysis in the alpha band, measured in terms of sensor-level imaginary part of coherence values between prefrontal and posterior regions, suggested that the early sensory level enhancement measured in P1 may be top-down driven through alpha band long-range communication from prefrontal to posterior areas. Two potential higher-order processing related accounts were proposed for these findings (see the section *“Dual attention effect: integrative accounts”* below for an expanded discussion). However, the presented EEG data cannot distinguish among them or disentangle their potential relation to these results. Further research should address the relevance of these accounts for dual attention (see the section *“Limitations and future directions”* below for more details).

5.2. Dual attention effect: integrative accounts

Although the findings reported in this thesis suggest the dual attention effect is driven by an increased need for cognitive control (or an enhanced higher order information processing), and subsequent reduction in attention performance, when attending to the same spatial location with other individuals, the specific higher order process(es) involved are not clear at the present stage. Two main accounts were proposed based on the results presented in this thesis and considering related findings reported in literature. The first account (see the *“Mentalising or monitoring others”* section below) is social in nature, and strongly driven by visuospatial attention sharing with another individual. The second account (see the *“Response inhibition”* section below) has a mixed nature. According to the latter, the dual attention effect is not uniquely driven by sharing the attended locations with another person, but instead, may be elicited by an interplay between the attention sharing conditions and additional properties of the dual attention task (e.g., the unbalanced distribution of target stimuli, or the similarity/contingency between one’s and the partner’s target stimulus features).

These accounts are re-introduced below, followed by a discussion on the potential links between joint/shared attention and the dual attention effect.

5.2.1 Mentalising or monitoring others

It has been proposed that the knowledge of sharing the attended spatial location with another person may elicit extra higher order processes in relation to the other person (e.g., mentalising/monitoring), opening the possibility of attributing social behaviours to the co-attending individual, increasing the perceived bonding/affiliation/closeness (Wolf, Launay, & Dunbar, 2016; see also Shteynberg 2015, 2018). It would not be surprising that merely knowing that another person shares one's locus of attention could be equivalent to obtaining this information (about the other's attentional locus) by means of gaze following. Indeed, the context provided by the dual attention task echoes Tomasello et al.'s definition of joint attention, according to which, besides looking where others are looking, it is necessary that the individuals know that they are looking together to the same jointly attended objects (Tomasello et al., 2005). In the dual attention task, participants are sharing (or not) covert attention to a spatial location with another individual, while knowing that the other person is also attending (or not) to the same spatial location. This places dual attention as a covert version of joint attention, sharing one of its main components: the shared processing to the gazed location (or covertly attended location in current case). It is important to consider however, that joint and dual attention differ in important ways. Joint attention constitutes a complex process in which the interacting individuals need to detect and monitor the other's gaze, encode the gaze/head direction, and (re-)orient visual attention accordingly, while considering self and other's related information, and their relation to the environment (see Emery, 2000; Frischen, Bayliss, & Tipper, 2007; Langton, Watt, & Bruce, 2000; Nummenmaa & Calder, 2009 for reviews). This overt behavioural interplay between individuals supported on gaze monitoring/following is not present in dual attention.

Despite these differences, it was here speculated that the knowledge that another person shares one's attentional locus may induce the simulation of a joint attention-like spatial triangulation (i.e., in this case, a triangulation between one's covert attention deployment, the other's covert attention deployment, and the jointly attended spatial location), and the subsequent activation of the higher order processes supporting joint attention and facilitating coordination in the social world (e.g., monitoring others, mentalising; see Mundy & Newell, 2007; Tomasello, Carpenter, Call, Behne, & Moll, 2005). Accordingly, the dual attention related EEG evidence here presented may suggest the involvement of a brain region known to play a key role in both mentalising and monitoring others (i.e., the ACC). Both mid-frontal theta oscillations and the N2b event-related component, neural markers modulated by dual attention (Experiment 6), are known to be originated in the ACC (Cavanagh & Frank, 2014; Crottaz-Herbette & Menon, 2006; Ishii et al., 2014; Van Veen & Carter, 2002). The ACC has been linked (among multiple social/cognitive processes) to the processing of social information (Apps, Balsters, & Ramnani, 2012; Apps, Lockwood, & Balsters, 2013; Apps & Ramnani, 2014; Apps, Rushworth, & Chang, 2016). This brain region is activated when mentalising is required (Gallagher et al., 2000; Ruby & Decety, 2001; Van Overwalle, 2009), and plays an active role in monitoring others (Apps, Rushworth, & Chang, 2016; see also Williams, Waiter, Perra, Perrett, & Whiten, 2005 for a link between joint attention and mentalising networks in the brain). Hence, the above-mentioned N2b/theta oscillations findings could be taken as support for the involvement of joint attention-like higher order processes (i.e., mentalising and/or monitoring others) in dual attention (but it is not clear whether they could also be the outcome of other cognitive-control-related processes; see Chapter 4).

The additional resources devoted to these higher order processes (a secondary task) when attention is deployed to the same vs. different spatial locations than others individuals, may explain the reduced attention performance (in behaviour) in the former scenario (i.e., when sharing the attended spatial location), reflected in the dual attention effect. Yet, the simulation of the joint attention-like spatial triangulation may not occur when the task partner is not “physically reachable” to provide a spatial reference allowing the feasibility of the triangulation, possibly explaining the absence of a dual attention effect when the partner was performing the dual attention task from a separate room (Experiment 5) (contrary to task co-representation effects, shown to persists with remote co-actors; Atmaca et al., 2011; Heed et al., 2010; Ruys & Aarts, 2010; Sellaro et al., 2018; Tsai et al., 2008; Tufft et al., 2019; Wahn et al., 2017). Moreover, an equivalent triangulation simulation (and the related higher order processes) may be put into action regardless of the task partner’s social closeness (i.e., her group membership status, as examined in Experiment 4). Thus, it may be as useful to activate these higher order processes in relation to a task partner known to share one’s attentional locus regardless of her group membership status. Importantly however, the above-mentioned implications of the findings obtained in Experiments 4 and 5 should be treated with caution. As discussed in Chapter 3, it is not clear whether these findings correspond to experimental effects or to ineffective manipulations, and therefore, should be addressed carefully in followed-up experiments.

This leads to the final speculation regarding the dual attention effect and the *“mentalising or monitoring others”* account: Perhaps the (potential) additional resources devoted to these higher order processes when attention is deployed towards the same spatial locations with another individual may cause the behavioural reduction in attention performance measured by the dual attention effect (respect to the attention notshared condition). However, it could be the case that devoting resources to these processes may be beneficial for the individual in the social world. That is, the brain may be employing additional resources (reflected in this case by the stronger engagement of cognitive control, measured in the attention effects associated to the N2b event-related component and theta oscillations; but see also the enhanced early sensory processing measured in the P1 component attention effect) in order to properly address the contextual social needs, subsequently facilitating the interaction and coordination with other individuals (see Mundy & Newell, 2007; Tomasello, Carpenter, Call, Behne, & Moll, 2005).

5.2.2 Response inhibition account

It has been shown that evaluative pressure increases distractability by an irrelevant stimulus if the features of the irrelevant stimulus are contingent to the task set (Normand, Bouquet, & Croizet, 2014; see also Belletier, Normand, & Huguet, 2019). This interference was demonstrated to occur at the response selection stage, with the increased distraction deriving from a greater visuomotor priming from the irrelevant (but contingent) stimulus (Normand et al., 2014). In the context of the dual attention task, a task partner deploying covert attention towards the same spatial location one is focusing on could feel more threatening or could imply a higher evaluative potential than a partner attending to a different location. Following Normand and colleagues’ findings, the (potentially) higher evaluative pressure for the attention shared condition could also lead to higher distractability due to contingent interference at the response selection stage. Aligned with this hypothesis, mid-frontal theta power showed a stronger attention effect for the attention shared condition (Experiment 6), providing potential evidence for response-stage interference in the dual attention task (see Mückschel et al., 2017; note however, that this finding could be related to many other cognitive control processes beyond response inhibition, see Cavanagh & Frank, 2014 for a review). In this case, the contingent interference would arise from the task partner's targets (i.e., from stimuli sharing a key feature of one's task set -the stimulus size), leading to an enhanced response priming that needs to be inhibited. That is, for the attention shared condition, the partner's targets would more strongly prime one's own target-relevant response, with a subsequently higher need to inhibit this primed response given one's instructions set, respect to the condition in which the locus of attention was notshared by the dyad. This would explain the behavioural attention performance drop (measured as a reduced attention effect) for the attention shared condition in the dual attention task. Moreover, another person performing the dual attention task remotely may not feel threatening/evaluative any more (see Belletier, Normand, & Huguet, 2019), possibly explaining the absence of the dual attention effect when the task partner is in a separate room (Experiment 5; this finding must be treated with caution and followed-up in future experiments).

As a reminder, the presented EEG data showed a reduced attention effect in the N2b event-related component when attention was shared than notshared by the dyad while completing the dual attention task, mirroring the behavioural attention performance reduction presented in Chapter 2. Similarly, a stronger mid-frontal theta band power attention effect was obtained when the dyad shared the locus of attention, relative to the notshared condition. These results could be linked to any of the above-mentioned higher order processes (i.e., mentalising/monitoring, and response inhibition) potentially explaining the dual attention effect. However, as previously discussed (above and in Chapter 4), the present EEG data cannot discriminate among these accounts, discarding or supporting a specific one. Considerations in this regard will be discussed below in the section *“Limitations and future directions”*.

5.2.3 Joint attention, shared attention and dual attention

As presented in previous sections of this thesis, shared attention has been proposed as a psychological state that implies the activation of a collective perspective when experiencing the world with others (Shteynberg, 2015, 2018). It represents the activation of a “we mode” in which one's perspective is also the other person's perspective, they become a collective one. It has been proposed that this “we mode” (i.e., the sole knowledge that other individuals are co-attending to the same objects or tasks with us) could cause more cognitive resources to be allocated to the co-attended objects or tasks, resulting in better performance in general (Shared attention theory; Shteynberg, 2015, 2018). However, the specific role of the attended spatial locations and its relation to attention performance has not been considered by the shared attention field. The findings presented in this thesis suggest that the proposal by the shared attention theory may not be enough to explain the changes in attention performance obtained when sharing vs. not sharing the visuospatial locus of attention with another individual. In line with the shared attention theory, overall faster responses where obtained when performing the dual attention task in dyads (Exp1) than when performing alone (Exp2). This outcome could be interpreted (in line with the shared attention theory) as an improved performance when sharing attention to the same task with the task partner, respect to performance in isolation. However, as argued in the previous chapters, the shared attention theory cannot account for the dual attention effect obtained in the dyadic setting.

Moreover, the presented findings suggest that dual attention and shared attention mechanisms differ in the way they are modulated by social context. The evidence supporting the shared attention theory has consistently shown the enhanced cognitive processing effects exclusively when co-attending with in-group members. In contrast, the dual attention effect was already present when participants performed the dual attention task with strangers (e.g., Experiments 1 and 3, described in Chapter 2), and was not modulated by the task partner's group membership status, at least as induced in Experiment 4 (although caution is encouraged when considering this finding). Similarly, the "we-mode" elicited by shared attention is present when the co-attending individuals are located remotely, but the dual attention effect disappeared when performing the dual attention task with a partner in a separate room (Experiment 5; a finding that must be treated with caution and followed-up in future experiments). Therefore, the evidence discussed in this thesis in relation to the shared attention theory and the dual attention effect, could suggest that no single mechanism underlies "sharing attention" with others in the social world, and that instead, different mechanisms/processes may be called in to action depending on the specific social/cognitive context. In this line, dual attention could be seen as an added layer to the general shared attention framework (Stheynberg 2015, 2018). That is, despite people's shared or not attentional locus in the dual attention task, they would be always "sharing attention" according to the shared attention framework. The task here proposed (and this thesis in general) however, investigated a further and more specific manipulation of attention performance under different "shared attention" status (i.e., depending on whether particular spatial locations were shared or not by the individuals). This additional request seems to be supported by mechanisms beyond those underlying the "we-mode" characterising shared attention.

Considering the *"Mentalising or monitoring others account"* presented above, the dual attention effect could be seen as a covert version of joint attention (but see the *"Response inhibition account"* above). Joint attention, has been simply defined as "looking where others are looking" (Butterworth, 1995, p. 29), and its implications have been intensively studied from both psychological and philosophical perspectives (Siposova & Carpenter, 2019). This investigation however, has been mostly focused on its relation to cooperation, bonding, theory of mind, and social learning (Mundy & Newell, 2007; Siposova & Carpenter, 2019; Tomasello et al., 2005; Tomasello et al., 2012), without consideration for the specific role of the attended spatial locations and its relation to attention performance (as was the case for the shared attention theory). The dual attention effect here introduced extended this knowledge by describing the attention performance changes when sharing or not the covert visuospatial locus of attention with others, rather than focusing exclusively on the higher level implications typically addressed in the joint attention literature, and excluding the overt behavioural interplay between individuals involved in joint attention (i.e., monitoring the other's gaze, encoding the gaze/head direction, and (re-)orienting overt visual attention accordingly, while considering self and other's related information, and their relation to the environment; Emery, 2000; Frischen, Bayliss, & Tipper, 2007; Langton, Watt, & Bruce, 2000; Nummenmaa & Calder, 2009). Moreover, the insights here provided may suggest an interplay between the low-level cognitive aspects addressed by dual attention (i.e., attention performance), and the more overt and higher level processes typically related to joint attention (see the *"Mentalising or monitoring others"* account above). Yet, the mechanisms behind this interplay between low-level cognitive processes, the cognitive control processes involved, and the implications of social contexts beyond those here addressed (i.e., the task partner's social/physical closeness), remain to be understood.

Overall, social interactions seem to be more complex than the description provided by the "joint attention" and the "shared attention" frameworks. Different processes are involved when co-attending to objects/task/experiences/locations with other individuals, and in this regard, dual attention represents an important link between the shared attention and the joint action/joint attention perspectives. The former addresses exclusively the psychological status of sharing a experience with others (i.e., a "we-mode" derived from the sole knowledge that other individuals are co-attending to the same objects/tasks/experience), while the latter addresses the overt behavioural interplay between individuals (i.e., supported on gaze following). The current component (i.e., dual attention) bridges these two frameworks by suggesting that people develop a different mental status about how to mentalise and/or represent the social interaction scenarios without being engaged in overt physical interactions while co-attending to the world with others.

5.3. Dual attention effect: real-life implications

At this point, the reader may wonder about the implications of the current findings and how they could be relevant in real-life scenarios. Are people actually engaged in dual attention situations in real life? In line with this question, imagine for example, a group of students attending together to a lecture, a couple of workers monitoring a product in an industrial assembly chain (or monitoring a process on a screen), or even two persons playing a board game. In all these tasks/situations, people are checking one source of information together, at specific and known spatial locations, without discussing or interacting. Hence, these examples represent dual attention-like settings, and the current findings could inform us about how people's brains behave in these and similar situations. In all these examples it would be plausible to expect, echoing the dual attention findings, a sensory processing enhancement to give priority to the shared information (see the P1 event-related results in Experiment 6), and a behavioural reduction in the visuospatial attention benefit, as a result of a control mechanism (see for instance, the behavioural dual attention effect presented in Experiment 1 and the related cognitive control evidence in the N2b component and theta oscillations presented in Experiment 6). As introduced above, both the sensory level enhancement and the stronger need for cognitive control linked to dual attention may be beneficial in these social settings. The sensory level enhancement would allow a preferential processing of the (potentially more informative/relevant) information at the co-attended location, while the greater resources dedicated to cognitive control processes may allow an adequate response to the contextual social needs, facilitating the potential interaction with other individuals (see the *"Mentalising and monitoring others"* account described above). Thus, the present results could have ubiquitous real-life implications, and following them up becomes highly relevant. Indeed, following-up the current findings (e.g., by employing more interactive paradigms in more realistic scenarios) could improve our understanding about how attention is shaped by sharing our reality with others in many daily-life scenarios like those described above (i.e., classrooms, workspaces), and may for instance, give us some clues about how to optimize performance in these dual-attention-like environments.

5.4. Limitations and future directions

5.4.1 Conceptual similarity across tasks in the dual attention paradigm

It remains to be answered whether this interpersonal influence in attention is always present, or whether it is supported by the conceptual similarity of the task at hand. In the dual attention paradigm, dyads are responding to target's shapes/sizes while sharing or not the attended locations. It may be that another person's locus of attention only matters (or interferes with one's performance) when other aspects/dimensions/features of the task are also relevant or shared by the dyad (e.g., see the response inhibition account discussed above). A follow-up experiment could test this notion by manipulating the target-stimulus feature-components so that they are shared or not by the dyad while performing the dual attention task.

5.4.2 The role of perceptual load

Although perceptual load did not seem to play a relevant modulating role in the interpersonal influence measured in dual attention (see Exp 3 and Exp 6), one may argue that in these experiments the perceptual load was not adequately controlled. Indeed, individual differences were not assessed, and these differences have been shown to modulate the effects of task load (Murphy et al., 2016). Therefore, it could be the case that the proposed perceptual load manipulation did not affect every participant in exactly the same way. A potential way of fitting the task to each participant could be to use a stair-case-like procedure (Dixon & Mood, 1948; see also Read, 2015), adapting the task load according to a specific individual performance threshold. After obtaining the individual load parameters (in this case the similarity between targets and non-targets) for the respective thresholds, the task load could be decided for the dyad accordingly (e.g., using the average load for the pair, using the lowest one, or using different load settings for the two participants in each pair; see also Handy & Mangun, 2000, who set the accuracy to be always 75% for each participant by changing the stimuli online). This would reduce the inter-subject variability in the perceptual load manipulation, and may provide more accurate insights about the role of perceptual load in the dual attention effect, if any.

The finding that the dual attention effect remains unaffected under an increased perceptual load (Exp 3) could also be taken to suggest that the effect is automatic in terms of efficiency (i.e., an efficient process; Melnikoff & Bargh, 2018; Moors, 2016; Moors & De Houwer, 2006; Shiffrin & Schneider, 1977). This would add to the body of literature suggesting automaticity as a core feature of social-cognitive processes (Bargh et al., 2012; Bargh & Williams, 2006). Stereotyping (Bargh & Williams, 2006), implicit theory of mind (Schneider, Lam, Bayliss, & Dux, 2012), imitative behaviours (Ramsey, Darda, & Downing, 2019), and gaze-induced joint attention (Frischen et al., 2007), are processes said to be deployed in an automatic manner. The former two (i.e., stereotyping and implicit theory of mind) have been shown to occur unintentionally (although inefficiently) (Gilbert & Hixon, 1991; Schneider et al., 2012), while the latter two (i.e., imitative behaviours and gaze-triggered attention shifts) are both unintentional and efficient behaviours (Frischen et al., 2007; Ramsey et al., 2019; Xu et al., 2011). It is important to note that both gaze-induced joint attention and the dual attention effect seem to be resistant to load. These evidence together may suggest that efficiency is a characteristic of the information processing involved in co-attending to the world with other individuals. Investigating the remaining dimension of automaticity (i.e., intentionality, controllability and consciousness; Melnikoff & Bargh, 2018; Moors & De Houwer, 2006) in relation to the dual attention effect would valuably extending the current understanding of this interpersonal effect.

5.4.3 Eye movements and the dual attention effect

It is important to mention that controlling eye-movements is always recommended in attention-related experiments to avoid any possible confound from foveal processing of the stimuli, which is faster and more precise than the peripheral non-foveal counterpart (Chica, Martín-Arévalo, Botta, & Lupiáñez, 2014). In the experiments presented in this thesis, even if participants were instructed to keep a constant central fixation, eye movements were not monitored and therefore the central fixation could not be taken for granted. Given that the attention/trial validity employed (e.g., 75% of the target stimuli appearing at the attended side of the screen) biases attention towards the instructed attended hemifield, even if participants performed systematic eye movements towards the locations were the stimuli were displayed, this would only be reflected in overall changes in the reaction times distributions respect to the covert attention performance, but would not affect the attention effect modulations reported the thesis. Alternatively, if participants instead looked directly at the attended location, RT to valid trials would be much faster, and RT to invalid trials much slower, respect to a central fixation scenario, leading to a larger attention effect . This attention effect could only be stronger for the shared condition (i.e., when the two persons' tasks were inducing gaze shifting in the same direction) than for the notshared condition. In this case, gaze shifting would induce a larger attention effect for the shared condition, a prediction contradicting the current results. Following these arguments, even if eye-movements were not monitored, it seems unlikely for eye-movements to explain the dual attention effect. The discussion about the need to measure eye movements will be extended below, when addressing the limitations and future directions for EEG studies in relation to dual attention.

5.4.4 Examining the role of arousal and social anxiety

One may suggest that changes in arousal could be related to the dual attention effect. An increased impairment of executive attention or cognitive control has been found when merely-present individuals are considered a threat that needs to be monitored (Huguet, et al., 2014), or when they represent an evaluative potential (Belletier et al., 2015). In the context of the dual attention task, a task partner deploying covert attention towards the same spatial location one is focusing on could feel more threatening or could imply a higher evaluative potential than a partner attending to a different location. This would direct more executive resources towards monitoring the co-attending task partner, reducing the attention capacity (that would be otherwise used for other activities like the task at hand) in respect to the condition in which this task partner does not share the locus of attention. The reduction in the attention capacity for the attention shared condition could be potentially related to the attention performance drop measured by the dual attention effect (but note that the shared-condition-related enhancement in the P1 component attention effect could not be explained by this capacity reduction hypothesis). Given that relationship between arousal and evaluative threats (e.g., Bosch et al., 2009), measuring the changes in the physiological levels of arousal (e.g., associated to the heart rate, blood pressure, and galvanic skin responses) across attention sharing conditions may be an interesting path for future studies. Nonetheless, it is important to consider that an arousal account may not seem as clear from the perspective of the shared attention theory (e.g., Shteynberg, 2015, 2018). Shteynberg (2015) proposed that tasks may not always be the object of shared attention. Shteynberg suggested that under some circumstances (e.g., if the other person is not working on the task, but just watching one's performance), this focus could shift from one's task to one's performance, leading to increased resources deployed to monitor one's performance, potentially driving an increase in arousal/anxiety (e.g., Geen, 1991). But, as discussed by Shteynberg (2015), and in consonance with the classic social facilitation literature (e.g., Zajonc, 1965), an increased drive or arousal would lead to enhanced performance for easy tasks, like the one here performed, which was not the case. Further research should address the actual role of arousal (if any) in the interpersonal effect here discussed.

In order to study the potential relationship between individual differences in anxiety and the dual attention effect, participants completed the *State-Trait Anxiety Inventory* (STAI; Spielberger, 2012). This questionnaire assessed participants trait (i.e., how anxious participants generally felt) and state anxiety (i.e., how anxious they felt at the moment of answering the questionnaire). The questionnaire's scores however, did not correlate with the dual attention effect measured behaviourally. Perhaps, future experiments should employ social anxiety measures instead, since these would more directly relate to the interpersonal context here investigated. For instance, the Social Anxiety Questionnaire for adults (SAQ; Caballo et al., 2015), the Social Interaction Anxiety Scale (SIAS; Mattick & Clarke, 1998) or the self-report version of the Leibowitz Social Anxiety Scale (LSAS; Fresco et al., 2001; Liebowitz, 1987) could be considered.

5.4.5 Social context manipulations

Chapter 3 examined whether the social "closeness" (operationalised by a minimal group manipulation) and the physical "closeness" (i.e., performing with a partner in a remote location) among task partners modulated the interpersonal influence measured in the dual attention task. Although the proposed minimal group manipulation did not alter this interpersonal influence, it is plausible to consider that alternative manipulations of social context could be strong enough to actually moderate the effect of dual attention. In the joint action literature, experiments employing real groups involving race (e.g., black vs. white; Müller et al., 2011), and social status (e.g., albanian vs. italian participants; Aquino et al., 2015), successfully moderated co-representation levels in dyads. Positive/negative interdependence related manipulations also proved “successful” in this regard (He et al., 2011; Hommel et al., 2009). Social status was also shown to be a relevant aspect of social context modulating the interpersonal influence on basic cognitive processes related to spatial orienting (Gobel, Tufft, & Richardson, 2018). All these constituted clear examples of cognitive processes being shaped by social context in joint performance. Therefore, dual attention related follow-up experiments manipulating social context by any of these means (i.e., social status, racial groups, or interdependence/competition) could provide additional insights about the role of social context on the dual attention effect.

The role of physical closeness deserves further attention and should also be followed-up in future experiments. As discussed above, although the findings here reported favoured the absence of the dual attention effect when performing with a partner in a separate room, the attention performance variations by the attention sharing with the task partner in a remote location (Exp 5) were still remarkably different than the performance in isolation (Exp2) (i.e., the dual attention effect was reversed in Exp2 and disappeared in Exp5). This outcome may suggest a social influence in attention performance anyway (but see Exp5 for a discussion regarding how the differences in the task properties could also be related to the above-mentioned modulations in performance). Whether the difference between “remote” performance and performance in isolation arises due to an interpersonal social influence or due to differences in the task parameters employed should be properly addressed given the potential social implications deriving from this finding (e.g., consider that the current mass/social media ecosystem allows for this scenario to occur with multiple individuals in a daily basis). In this line, examining whether attention performance is modulated by the number of task partners sharing (or not) one’s attended spatial locations (i.e., group size) in remote performance settings becomes an additional intriguing question that needs to be addressed.

5.4.6 The role of the anterior cingulate cortex in dual attention

Experiment 6 found neural markers of dual attention in midfrontal theta oscillations and the N2b event-related component. These neural signatures have been previously shown to be originated in the mPFC, particularly in the ACC (Cavanagh & Frank, 2014; Crottaz-Herbette & Menon, 2006; Ishii et al., 2014; Van Veen & Carter, 2002). The ACC is implicated in a wide range of cognitive processes (Van Veen & Carter, 2002; Vassena, Holroyd, & Alexander, 2017), including the processing of social information (Apps, Balsters, & Ramnani, 2012; Apps, Lockwood, & Balsters, 2013; Apps & Ramnani, 2014; Apps, Rushworth, & Chang, 2016). Of particular relevance to the current research are the roles of the anterior cingulate gyrus (ACCg) and the anterior cingulate sulcus (ACCs or dACC- dorsal ACC). The ACCg seems to play a key role in processing, monitoring and predicting other's mental states (Apps, Balsters, & Ramnani, 2012; Apps, Lockwood, & Balsters, 2013; Apps & Ramnani, 2014; Apps, Rushworth, & Chang, 2016). Indeed, it has been suggested that this area processes information in an "other-oriented" reference frame, responding to "other-oriented" information but not to information relevant to the self (Apps, Rushworth, & Chang, 2016). On the other hand, a similar role has been attributed to the ACCs in relation to self relevant information (Apps, Rushworth, & Chang, 2016). Future experiments could address the potential roles of the ACCg and the ACCs in relation to the dual attention effect, and their interaction to the attention and control networks in the brain. In addition, multimodal imaging (e.g., fMRI-EEG, or MEG informed by structural MRI) could investigate whether the theta band oscillations here reported are generated in (or related to) these specific areas. Moreover, it has been shown that joint attention (as compared to dis-joint attention/averted gaze) more strongly activates brain networks related to both mentalising (Williams, Waiter, Perra, Perrett, & Whiten, 2005) and processing rewards (Gordon et al., 2013; Pfeiffer et al., 2014; Schilbach et al., 2010). Following the latter, it has been proposed that joint attention is a socially more rewarding experience than disjoint attention (Gordon et al., 2013). This idea could be investigated in future studies in relation to dual attention (e.g., examining whether manipulating rewards modulates the dual attention effect and the ACC response).

5.4.7 Alpha and theta oscillations in dual/joint attention

Experiment 6 also speculated about the potential roles of alpha and theta oscillations when attending to the world with others. It seems that those paradigms employing a typical gaze-cueing task dynamic have shown changes in alpha oscillations linked to joint attention (Hoehl et al., 2014; Lachat et al., 2012; Michel et al., 2015; Rayson et al., 2019), whereas those paradigms where eye contact and gaze following did not seem to play an essential role showed modulations in theta oscillatory activity instead (e.g., in the dual attention task, and in the naturalistic setting used by Wass et al., 2018; see the Chapter 4 discussion). Perhaps, the increase in theta power is not directly related to gaze following, but to higher order processing induced by the knowledge of being simultaneously attending to the same locations with another person? Or perhaps alpha band modulations in joint attention are related to the reflexive nature of the gaze-cuing paradigms typically employed (Driver et al., 1999; Friesen & Kingstone, 1998; Langton, Watt, & Bruce, 2000; Xu, Zhang, & Geng, 2011)? Future research should address these thought provocative ideas.

5.4.8 Limitations of the present EEG design

Nonetheless, it is necessary to consider that the EEG experimental design employed in Chapter 4 (Exp 6) contains two important differences respect to the behavioural dual attention experiments presented in the previous chapters. In Experiment 6, a 50% target validity (instead of 75%) was employed, and the participants responded exclusively to targets appearing at the attended side of the screen (while in the previous experiments responses where made to both attended and unattended locations). In addition, to avoid contamination derived from manual responses, only electrophysiological responses to non-target stimuli (which doubled the number of target ones) were considered for analysis. All these choices although typical in the EEG literature (Cohen, 2014a; Luck, 2014), could raise some concerns about the current findings and limit the conclusions derived from them. For instance, one could say that the behavioural findings in relation to the attention effect for go-trials (i.e., the previous experiments) may not correspond to the attention effect measured in EEG for no-go trials. This seems unlikely in terms of attentional deployment. That is, one would expect that sustained attention would be deployed to one hemifield according to the task instructions, regardless of the type of stimulus displayed in a particular experimental trial (i.e., go vs. nogo stimuli). In terms of cognitive control however, nogo trials are known to require a stronger cognitive control than go trials (since the manual responses should be inhibited for nogo stimuli). This also means that stronger N2bs and frontal theta oscillations are typically obtained for nogo than go trials (Cavanagh & Frank, 2014). Although this could be an advantage in terms of signal-to-noise ratio for the nogo trials (since a stronger neural response is analysed), a potential interaction between the cognitive control needed to inhibit responses to nogo trials and the control process related to dual attention cannot be ruled out. A follow-up experiment should provide empirical evidence on this regard by comparing the neural correlates of dual attention for both go and no-go trials. Moreover, including the behavioural responses to attended and unattended stimuli would allow performing correlations between EEG and reactions times, shedding more light on the relationship between the neural responses here reported and behaviour in dual attention.

Moreover, the trial length used in Experiment 6, although prototypical for ERP analysis, is not ideal for time-frequency analysis, specially if interested in the lower side of the spectrum (e.g., the theta frequency range) (Cohen, 2014a). The current trial length limits the range of frequencies that could be studied without contamination from neighbour trials, as well as the choice of a safe baseline period (Cohen, 2014a). These issues are exacerbated for lower frequencies. Indeed, here these concerns led to the decision of considering only oscillations above 5Hz for analysis, instead of the full theta frequency range. A follow-up experiment should employ longer trials/epochs in order to validate and extend the present results in relation to the roles of alpha and theta oscillations in dual attention. Longer trials would not only deal with the concerns discussed above (and facilitate the study of lower frequencies), but would also increase the frequency-precision of the analysis, allowing the investigation of the role of more specific frequency ranges in the cognitive processes of interest (Cohen, 2014a). This would allow for instance, investigating the roles of the different alpha and theta sub-bands, considered to reflect different aspects of the underlying brain processes (Klimesch, Doppelmayr, Russegger, Pachinger, & Schwaiger, 1998; Mückschel, Dippel, & Beste, 2017) beyond the current results. As a relevant example, it has been suggested that stimulus and response codes in inhibitory control may be captured by different oscillations within the theta range, with stimulus codes linked to upper theta (~7Hz), and response codes to lower theta oscillations (~4Hz) (Mückschel et al., 2017).

Blinks and eye movements are known to exhibit spectral signatures in the delta and theta frequency range (Gasser, Sroka, & Möcks, 1986; Hagemann & Naumann, 2001). In the current experiment, electro-oculographic data (EOG) were not recorded. Therefore, no artifact rejection/correction method was applied based on information from bipolar EOG channels. This makes impossible to confidently conclude that EOG related activity did not influence the current findings. Nonetheless, it has been shown that the spectral energy associated with ocular activity decreases with increasing frequency, with most of this energy located below 5 Hz, and resulting insignificant above 7.5 Hz (Gasser et al., 1986; Hagemann & Naumann, 2001). Considering that in the current experiment only oscillations in the 5-7Hz frequency range (i.e., upper theta) were analysed, it could be argued that if there was any electrophysiological influence from eye movements at mid-frontal sites, it should be weak relative to the main physiological mid-frontal signature of cognitive control. Similarly, the topographic maps representing the activity in the time range of interest for the N2b (see *Figure 18*) and theta oscillations (see *Figure 22*) do not exhibit strong activations at the frontal-poles or fronto-temporal EEG channels (i.e., the sites where EOG related activity would be captured by the current setup), compared to the activity of interest measured at mid-frontal electrodes. Although this shows that the strongest electrophysiological activity in the analysed time ranges was indeed registered at the relevant fronto-central channels, this cannot rule out a weaker but existent influence from EOG signals in the times/sites of interest, nor whether this potential influence could be strong enough to explain the current findings. Future experiments, should record both vertical and horizontal EOG and apply the relevant correction/rejection methods (but see Quax, 2019, suggesting that simultaneous eye-tracking recordings may be necessary to deal with eye movement artifacts, including saccades and micro-saccades, in visual attention tasks; see also Strukelj, Foulsham & Nyström, 2016, for evidence showing that social context can modulate basic oculomotor activity, at least when performing antisaccades). Moreover, as suggested in (Hari & Puce, 2017), it would be ideal to average the EOG channels in the same way as the EEG electrodes, in order to allow meaningful comparisons across the experimental conditions.

5.4.9 Hyperscanning research

The hyperscanning technique (i.e., the simultaneous/synchronised measurement of brain activity from multiple subjects; Montague, 2002) has gained popularity in recent years, and multiple studies have been reported employing synchronised EEG, MEG, fMRI and fNIRS measurements (aka. dual EEG/MEG/fMRI/fNIRS) to investigate different facets of social cognition (e.g., interpersonal coordination, social/joint/shared attention, coordinated movement, speech coordination, mental coordination, coordinated activities in social and ecological contexts, interactive decision-making, affective communication, etc (see Koike, Tanabe, & Sadato, 2015; Liu et al., 2018; Mu, Cerritos, & Khan, 2018; Wang et al., 2018; Zhang, 2018 for recent reviews). In joint/social attention research, dual-EEG has been used to study multiple subjects simultaneously both in the lab and in more naturalistic scenarios (e.g., a classroom), providing some initial insights regarding potential oscillatory intra and inter-brain correlates (mainly in the alpha and theta frequency bands) of attending to the world with others (e.g., Dikker et al., 2017; Lachat et al., 2012; Leong et al., 2017; Szymanski et al., 2017; Wass et al., 2018; see Chapter 1 for more details). Examining whether these inter-brain connectivity patterns are also markers of dual attention, or whether our brains are more (or less) synchronised when sharing the locus of attention with others, would be interesting research avenues.

Experiment 6 already employed a dual-EEG set-up to record EEG data simultaneously from the dyads taking part in the dual attention task. However, considering that most of the connectivity methods employed to date in a hyper-scanning context are carried out in the frequency-domain (see Burgess, 2013), it would be prudent to perform the related inter-brain analysis in a follow-up study, after addressing the design concerns introduced above. Moreover, even though the new insights provided by the hyperscanning technique are certainly promising, it is important to mention that the physiological/psychological interpretation of the findings is not clear, nor the origins of inter-brain synchronicity and the factors influencing/modulating it (Burgess, 2013; Hari, Henriksson, Malinen, & Parkkonen, 2015). In addition, in order to get the most out of the hyperscanning technique/data, more real-life-like experimental paradigms need to be devised, and further developments are required from the analysis methods side (Burgess, 2013; Hari, Henriksson, Malinen, & Parkkonen, 2015).

5.5. Final remarks

Finally, the evidence presented in this thesis suggests interpersonal influences on basic attentional mechanisms. Particularly, when attending to the same spatial locations with other individuals, an enhanced sensory level attention effect, followed by an increased need for cognitive control and a subsequent behavioural reduction in attention performance were here obtained. This adds to the body of literature suggesting that even the most basic cognitive processes can be modulated by social context and by other people in our environment (e.g., Gobel et al., 2015, 2018; He et al., 2011; Sebanz et al., 2003; Stheynberg., 2015, 2018; Tufft et al., 2019). The current findings also show that in order to understand the social facets of the human brain, not only the social components of the information processed should be considered, but also the interplay between social and cognitive processes should be addressed. Moreover, although speculative at the current stage, these findings could potentially have ubiquitous real-life implications (e.g., for classrooms and working environments; see the section *“Dual attention effect: real-life implications”* above), and could allow, in the long run, to develop strategies aimed at better understanding and treating related clinical conditions (e.g., ADHD, Neglect syndrome). With this in mind, following-up the present PhD work in order asses its real-life implications acquires tremendous relevance.

References

Adrian, E. D., & Matthews, B. H. C. (1934a). The Berger Rhythm: Potential changes from the occipital lobes in man. *Brain*, *57*(4), 355–385. https://doi.org/10.1093/brain/57.4.355

Adrian, E. D., & Matthews, B. H. C. (1934b). The interpretation of potential waves in the cortex. *The Journal of Physiology*, *81*(4), 440–471. https://doi.org/10.1113/jphysiol.1934.sp003147

Aiello, J. R., & Douthitt, E. A. (2001). Social facilitation from Triplett to electronic performance monitoring. *Group Dynamics: Theory, Research, and Practice, 5*(3), 163–180. https://doi.org/10.1037/1089-2699.5.3.163

Alexander, W. H., Vassena, E., Deraeve, J., & Langford, Z. D. (2017). Integrative Modeling of Prefrontal Cortex. *Journal of Cognitive Neuroscience*, *29*(10), 1674–1683. https://doi.org/10.1162/jocn_a_01138

Allport, F. (1924). *Social psychology*. New York: Houghton Mifflin Company.

Amodio, D. M., & Frith, C. D. (2006). Meeting of minds: The medial frontal cortex and social cognition. *Nature Reviews Neuroscience*, *7*(4), 268–277. https://doi.org/10.1038/nrn1884

Andreu, C. I., Palacios, I., Moënne-Loccoz, C., López, V., Franken, I. H. A., Cosmelli, D., & Slagter, H. A. (2019). Enhanced response inhibition and reduced midfrontal theta activity in experienced Vipassana meditators. *Scientific Reports*, *9*(1), 13215. https://doi.org/10.1038/s41598-019-49714-9

Apps, M. A. J., & Ramnani, N. (2014). The Anterior Cingulate Gyrus Signals the Net Value of Others' Rewards. *Journal of Neuroscience*, *34*(18), 6190–6200. https://doi.org/10.1523/JNEUROSCI.2701-13.2014

Apps, M. A. J., Balsters, J. H., & Ramnani, N. (2012). The anterior cingulate cortex: Monitoring the outcomes of others' decisions. *Social Neuroscience*, *7*(4), 424–435. https://doi.org/10.1080/17470919.2011.638799

Apps, M. A. J., Lockwood, P. L., & Balsters, J. H. (2013). The role of the midcingulate cortex in monitoring others' decisions. *Frontiers in Neuroscience*, *7*. https://doi.org/10.3389/fnins.2013.00251

Apps, M. A. J., Rushworth, M. F. S., & Chang, S. W. C. (2016). The Anterior Cingulate Gyrus and Social Cognition: Tracking the Motivation of Others. *Neuron*, *90*(4), 692–707. https://doi.org/10.1016/j.neuron.2016.04.018

Aquino, A., Paolini, D., Pagliaro, S., Migliorati, D., Wolff, A., Alparone, F. R., & Costantini, M. (2015). Group membership and social status modulate joint actions. *Experimental Brain Research*, *233*(8), 2461–2466. https://doi.org/10.1007/s00221-015-4316-7

Aron, A., Aron, E. N., & Smollan, D. (1992). Inclusion of Other in the Self Scale and the structure of interpersonal closeness. *Journal of Personality and Social Psychology*, *63*(4), 596–612. https://doi.org/10.1037/0022-3514.63.4.596

Astolfi, L., Toppi, J., De Vico Fallani, F., Vecchiato, G., Cincotti, F., Wilke, C., … Babiloni, F. (2011). Imaging the Social Brain by Simultaneous Hyperscanning during Subject Interaction. *IEEE Intelligent Systems*, *26*(5), 38–45. https://doi.org/10.1109/MIS.2011.61

Atmaca, S., Sebanz, N., & Knoblich, G. (2011). The joint flanker effect: Sharing tasks with real and imagined co-actors. *Experimental Brain Research*, *211*(3–4), 371–385. https://doi.org/10.1007/s00221-011-2709-9

Atmaca, S., Sebanz, N., Prinz, W., & Knoblich, G. (2008). Action co-representation: The joint SNARC effect. *Social Neuroscience*, *3*(3–4), 410–420. https://doi.org/10.1080/17470910801900908

Azizian, A., Freitas, A. L., Parvaz, M. A., & Squires, N. K. (2006). Beware misleading cues: Perceptual similarity modulates the N2/P3 complex. *Psychophysiology*, *43*(3), 253–260. https://doi.org/10.1111/j.1469-8986.2006.00409.x

Babiloni, F., Cincotti, F., Mattia, D., Mattiocco, M., Fallani, F. D. V., Tocci, A., ... & Astolfi, L. (2006). Hypermethods for EEG hyperscanning. In *2006 International Conference of the IEEE Engineering in Medicine and Biology Society* (pp. 3666-3669). IEEE.

Baccalá, L. A., & Sameshima, K. (2001). Partial directed coherence: A new concept in neural structure determination. *Biological Cybernetics*, *84*(6), 463–474. https://doi.org/10.1007/PL00007990

Baess, P., & Prinz, W. (2015). My partner is also on my mind: Social context modulates the N1 response. *Experimental Brain Research*, *233*(1), 105–113. https://doi.org/10.1007/s00221-014-4092-9

Bargh, J. A., & Williams, E. L. (2006). The Automaticity of Social Life. *Current Directions in Psychological Science*, *15*(1), 1–4. https://doi.org/10.1111/j.0963-7214.2006.00395.x

Bargh, J. A., Schwader, K. L., Hailey, S. E., Dyer, R. L., & Boothby, E. J. (2012). Automaticity in social-cognitive processes. *Trends in Cognitive Sciences*, *16*(12), 593–605. https://doi.org/10.1016/j.tics.2012.10.002

Baron, R. S., Moore, D., & Sanders, G. S. (1978). Distraction as a source of drive in social facilitation research. *Journal of Personality and Social Psychology, 36*(8), 816–824. https://doi.org/10.1037/0022-3514.36.8.816

Barraza, P., Dumas, G., Liu, H., Blanco-Gomez, G., van den Heuvel, M. I., Baart, M., & Pérez, A. (2019). Implementing EEG hyperscanning setups. *MethodsX*, *6*, 428–436. https://doi.org/10.1016/j.mex.2019.02.021

Bastos, A. M., & Schoffelen, J.-M. (2016). A Tutorial Review of Functional Connectivity Analysis Methods and Their Interpretational Pitfalls. *Frontiers in Systems Neuroscience*, *9*. https://doi.org/10.3389/fnsys.2015.00175

Bauer, M., Stenner, M.-P., Friston, K. J., & Dolan, R. J. (2014). Attentional Modulation of Alpha/Beta and Gamma Oscillations Reflect Functionally Distinct Processes. *Journal of Neuroscience*, *34*(48), 16117–16125. https://doi.org/10.1523/JNEUROSCI.3474-13.2014

Baumeister, R. F., Bratslavsky, E., Finkenauer, C., & Vohs, K. D. (2001). Bad is Stronger than Good. *Review of General Psychology*, *5*(4), 323–370. https://doi.org/10.1037/1089-2680.5.4.323

Beck, D. M., & Kastner, S. (2009). Top-down and bottom-up mechanisms in biasing competition in the human brain. *Vision Research*, *49*(10), 1154–1165. https://doi.org/10.1016/j.visres.2008.07.012

Belletier, C., Normand, A., & Huguet, P. (2019). Social-Facilitation-and-Impairment Effects: From Motivation to Cognition and the Social Brain. *Current Directions in Psychological Science*, *28*(3), 260–265. https://doi.org/10.1177/0963721419829699

Benedek, M., Bergner, S., Könen, T., Fink, A., & Neubauer, A. C. (2011). EEG alpha synchronization is related to top-down processing in convergent and divergent thinking. *Neuropsychologia*, *49*(12), 3505–3511. https://doi.org/10.1016/j.neuropsychologia.2011.09.004

Benoni, H. (2018). Can automaticity be verified utilizing a perceptual load manipulation? *Psychonomic Bulletin & Review*, *25*(6), 2037–2046. https://doi.org/10.3758/s13423-018-1444-7

Berger, H. (1929). Über das Elektrenkephalogramm des Menschen. *Archiv für Psychiatrie und Nervenkrankheiten*, *87*(1), 527–570. https://doi.org/10.1007/BF01797193

Böckler, A., & Sebanz, N. (2012). A co-actor's focus of attention affects stimulus processing and task performance: An ERP study. *Social Neuroscience*, *7*(6), 565–577. https://doi.org/10.1080/17470919.2012.682119

Böckler, A., Knoblich, G., & Sebanz, N. (2012). Effects of a coactor's focus of attention on task performance. *Journal of Experimental Psychology: Human Perception and Performance*, *38*(6), 1404–1415. https://doi.org/10.1037/a0027523

Bosch, J. A., de Geus, E. J., Carroll, D., Goedhart, A. D., Anane, L. A., van Zanten, J. J., … Edwards, K. M. (2009). A general enhancement of autonomic and cortisol responses during social evaluative threat. *Psychosomatic medicine*, *71*(8), 877–885. doi:10.1097/PSY.0b013e3181baef05

Bourgeois, A., Chica, A. B., Valero-Cabré, A., & Bartolomeo, P. (2013). Cortical control of inhibition of return: Causal evidence for task-dependent modulations by dorsal and ventral parietal regions. *Cortex*, *49*(8), 2229–2238. https://doi.org/10.1016/j.cortex.2012.10.017

Brennan, S. E., Chen, X., Dickinson, C. A., Neider, M. B., & Zelinsky, G. J. (2008). Coordinating cognition: The costs and benefits of shared gaze during collaborative search. *Cognition*, *106*(3), 1465–1477. https://doi.org/10.1016/j.cognition.2007.05.012

Brewer, M. B. (2007). The importance of being we: Human nature and intergroup relations. *American Psychologist*, *62*(8), 728–738. https://doi.org/10.1037/0003-066X.62.8.728

Brewer, M. B., & Yuki, M. (2007). Culture and social identity. In S. Kitayama & D. Cohen (Eds.), *Handbook of cultural psychology* (p. 307–322). Guilford Press.

Brunetti, M., Zappasodi, F., Marzetti, L., Perrucci, M. G., Cirillo, S., Romani, G. L., … Aureli, T. (2014). Do You Know What I Mean? Brain Oscillations and the Understanding of Communicative Intentions. *Frontiers in Human Neuroscience*, *8*. https://doi.org/10.3389/fnhum.2014.00036

Burgess, A. P. (2013). On the interpretation of synchronization in EEG hyperscanning studies: A cautionary note. *Frontiers in Human Neuroscience*, *7*. https://doi.org/10.3389/fnhum.2013.00881

Butterworth, G. (1995). Origins of mind in perception and action. In C. Moore & P. J. Dunham (Eds.), *Joint attention: Its origins and role in development* (p. 29–40). Lawrence Erlbaum Associates, Inc.

Buzsáki, G. (2004). Neuronal Oscillations in Cortical Networks. *Science*, *304*(5679), 1926–1929. https://doi.org/10.1126/science.1099745

Buzsáki, G. (2006). *Rhythms of the Brain*. https://doi.org/10.1093/acprof:oso/9780195301069.001.0001

Caballo, V. E., Arias, B., Salazar, I. C., Irurtia, M. J., Hofmann, S. G., & CISO-A Research Team (2015). Psychometric properties of an innovative self-report measure: The Social Anxiety Questionnaire for adults. *Psychological assessment*, *27*(3), 997–1012. https://doi.org/10.1037/a0038828

Capotosto, P., Babiloni, C., Romani, G. L., & Corbetta, M. (2012). Differential Contribution of Right and Left Parietal Cortex to the Control of Spatial Attention: A Simultaneous EEG-rTMS Study. *Cerebral Cortex*, *22*(2), 446–454. https://doi.org/10.1093/cercor/bhr127

Capotosto, P., Corbetta, M., Romani, G. L., & Babiloni, C. (2012). Electrophysiological Correlates of Stimulus-driven Reorienting Deficits after Interference with Right Parietal Cortex during a Spatial Attention Task: A TMS-EEG Study. *Journal of Cognitive Neuroscience*, *24*(12), 2363–2371. https://doi.org/10.1162/jocn_a_00287

Carrasco, M. (2011). Visual attention: The past 25 years. *Vision Research*, *51*(13), 1484–1525. https://doi.org/10.1016/j.visres.2011.04.012

Caruana, N., & McArthur, G. (2019). The mind minds minds: The effect of intentional stance on the neural encoding of joint attention. *Cognitive, Affective, & Behavioral Neuroscience*, *19*(6), 1479–1491. https://doi.org/10.3758/s13415-019-00734-y

Caruana, N., Brock, J., & Woolgar, A. (2015). A frontotemporoparietal network common to initiating and responding to joint attention bids. *NeuroImage*, *108*, 34–46. https://doi.org/10.1016/j.neuroimage.2014.12.041

Caruana, N., de Lissa, P., & McArthur, G. (2015). The neural time course of evaluating self-initiated joint attention bids. *Brain and Cognition*, *98*, 43–52. https://doi.org/10.1016/j.bandc.2015.06.001

Caruana, N., de Lissa, P., & McArthur, G. (2017). Beliefs about human agency influence the neural processing of gaze during joint attention. *Social Neuroscience*, *12*(2), 194–206. https://doi.org/10.1080/17470919.2016.1160953

Cavanagh, J. F., Cohen, M. X., & Allen, J. J. B. (2009). Prelude to and Resolution of an Error: EEG Phase Synchrony Reveals Cognitive Control Dynamics during Action Monitoring. *Journal of Neuroscience*, *29*(1), 98–105. https://doi.org/10.1523/JNEUROSCI.4137-08.2009

Cavanagh, James F., & Frank, M. J. (2014). Frontal theta as a mechanism for cognitive control. *Trends in Cognitive Sciences*, *18*(8), 414–421. https://doi.org/10.1016/j.tics.2014.04.012

Chapman, R. M., Ilmoniemi, R. J., Barbanera, S., & Romani, G. L. (1984). Selective localization of alpha brain activity with neuromagnetic measurements. *Electroencephalography and Clinical Neurophysiology*, *58*(6), 569–572. https://doi.org/10.1016/0013-4694(84)90047-6

Chatel-Goldman, J., Schwartz, J.-L., Jutten, C., & Congedo, M. (2013). Non-local mind from the perspective of social cognition. *Frontiers in Human Neuroscience*, *7*. https://doi.org/10.3389/fnhum.2013.00107

Chica, A. B., Bartolomeo, P., & Lupiáñez, J. (2013). Two cognitive and neural systems for endogenous and exogenous spatial attention. *Behavioural Brain Research*, *237*, 107–123. https://doi.org/10.1016/j.bbr.2012.09.027

Chica, A. B., Klein, R. M., Rafal, R. D., & Hopfinger, J. B. (2010). Endogenous saccade preparation does not produce inhibition of return: Failure to replicate Rafal, Calabresi, Brennan, & Sciolto (1989). *Journal of Experimental Psychology: Human Perception and Performance*, *36*(5), 1193–1206. https://doi.org/10.1037/a0019951

Chica, A. B., Martín-Arévalo, E., Botta, F., & Lupiáñez, J. (2014). The Spatial Orienting paradigm: How to design and interpret spatial attention experiments. *Neuroscience & Biobehavioral Reviews*, *40*, 35–51. https://doi.org/10.1016/j.neubiorev.2014.01.002

Ciulla, C., Takeda, T., & Endo, H. (1999). MEG characterization of spontaneous alpha rhythm in the human brain. *Brain topography*, *11*(3), 211-222.

Clark, V. P., Fan, S., & Hillyard, S. A. (1994). Identification of early visual evoked potential generators by retinotopic and topographic analyses. *Human Brain Mapping*, *2*(3), 170–187. https://doi.org/10.1002/hbm.460020306

Clayton, M. S., Yeung, N., & Cohen Kadosh, R. (2018). The many characters of visual alpha oscillations. *European Journal of Neuroscience*, *48*(7), 2498–2508. https://doi.org/10.1111/ejn.13747

Cohen, M. X. (2014a). *Analyzing neural time series data: Theory and practice*. Cambridge, Massachusetts: The MIT Press.

Cohen, M. X. (2014b). A neural microcircuit for cognitive conflict detection and signaling. *Trends in Neurosciences*, *37*(9), 480–490. https://doi.org/10.1016/j.tins.2014.06.004

Cohen, M. X. (2017). Where Does EEG Come From and What Does It Mean? *Trends in Neurosciences*, *40*(4), 208–218. https://doi.org/10.1016/j.tins.2017.02.004

Cohen, M. X. (2018). An Overview of Neural Time Series Analyses. In J. T. Wixted (Ed.), *Stevens' Handbook of Experimental Psychology and Cognitive Neuroscience* (pp. 1–17). https://doi.org/10.1002/9781119170174.epcn514

Cohen, M. X., & Cavanagh, J. F. (2011). Single-Trial Regression Elucidates the Role of Prefrontal Theta Oscillations in Response Conflict. *Frontiers in Psychology*, *2*. https://doi.org/10.3389/fpsyg.2011.00030

Cohen, M. X., & Donner, T. H. (2013). Midfrontal conflict-related theta-band power reflects neural oscillations that predict behavior. *Journal of Neurophysiology*, *110*(12), 2752–2763. https://doi.org/10.1152/jn.00479.2013

Cohen, M. X., & Ridderinkhof, K. R. (2013). EEG Source Reconstruction Reveals Frontal-Parietal Dynamics of Spatial Conflict Processing. *PLoS ONE*, *8*(2), e57293. https://doi.org/10.1371/journal.pone.0057293

Cole, G. G., Skarratt, P. A., & Billing, R.-C. (2012). Do action goals mediate social inhibition of return? *Psychological Research*, *76*(6), 736–746. https://doi.org/10.1007/s00426-011-0395-7

Colzato, L. S., Zech, H., Hommel, B., Verdonschot, R., van den Wildenberg, W. P. M., & Hsieh, S. (2012). Loving-kindness brings loving-kindness: The impact of Buddhism on cognitive self–other integration. *Psychonomic Bulletin & Review*, *19*(3), 541–545. https://doi.org/10.3758/s13423-012-0241-y

Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience*, *3*(3), 201–215. https://doi.org/10.1038/nrn755

Crottaz-Herbette, S., & Menon, V. (2006). Where and When the Anterior Cingulate Cortex Modulates Attentional Response: Combined fMRI and ERP Evidence. *Journal of Cognitive Neuroscience*, *18*(5), 766–780. https://doi.org/10.1162/jocn.2006.18.5.766

De Bruijn, E. R. A., Miedl, S. F., & Bekkering, H. (2008). Fast responders have blinders on: ERP correlates of response inhibition in competition. *Cortex*, *44*(5), 580–586. https://doi.org/10.1016/j.cortex.2007.09.003

De Jong, R., Liang, C.-C., & Lauber, E. (1994). Conditional and unconditional automaticity: A dual-process model of effects of spatial stimulus-response correspondence. *Journal of Experimental Psychology: Human Perception and Performance*, *20*(4), 731–750. https://doi.org/10.1037/0096-1523.20.4.731

De Schotten, M. T., Dell'Acqua, F., Forkel, S. J., Simmons, A., Vergani, F., Murphy, D. G. M., & Catani, M. (2011). A lateralized brain network for visuospatial attention. *Nature Neuroscience*, *14*(10), 1245–1246. https://doi.org/10.1038/nn.2905

Dennis, T. A., & Chen, C.-C. (2009). Trait anxiety and conflict monitoring following threat: An ERP study. *Psychophysiology*, *46*(1), 122–131. https://doi.org/10.1111/j.1469-8986.2008.00758.x

Desimone, R., & Duncan, J. (1995). Neural Mechanisms of Selective Visual Attention. *Annual Review of Neuroscience*, *18*(1), 193–222. https://doi.org/10.1146/annurev.ne.18.030195.001205

Di Russo, F. (2003). Source Analysis of Event-related Cortical Activity during Visuo-spatial Attention. *Cerebral Cortex*, *13*(5), 486–499. https://doi.org/10.1093/cercor/13.5.486

Di Russo, Francesco, & Pitzalis, S. (2014). EEG–fMRI Combination for the Study of Visual Perception and Spatial Attention. In *Cognitive Electrophysiology of Attention* (pp. 58–70). https://doi.org/10.1016/B978-0-12-398451-7.00005-1

Dikker, S., Wan, L., Davidesco, I., Kaggen, L., Oostrik, M., McClintock, J., … Poeppel, D. (2017). Brain-to-Brain Synchrony Tracks Real-World Dynamic Group Interactions in the Classroom. *Current Biology*, *27*(9), 1375–1380. https://doi.org/10.1016/j.cub.2017.04.002

Dixon, W. J., & Mood, A. M. (1948). A Method for Obtaining and Analyzing Sensitivity Data. *Journal of the American Statistical Association*, *43*(241), 109–126. https://doi.org/10.1080/01621459.1948.10483254

Doesburg, S. M., Bedo, N., & Ward, L. M. (2016). Top-down alpha oscillatory network interactions during visuospatial attention orienting. *NeuroImage*, *132*, 512–519. https://doi.org/10.1016/j.neuroimage.2016.02.076

Doise, W., Csepeli, G., Dann, H. D., Gouge, C., Larsen, K., & Ostell, A. (1972). An experimental investigation into the formation of intergroup representations. *European Journal of Social Psychology*, *2*(2), 202–204. https://doi.org/10.1002/ejsp.2420020208

Dolk, T., Hommel, B., Colzato, L. S., SchÃ¼tz-Bosbach, S., Prinz, W., & Liepelt, R. (2014). The joint Simon effect: a review and theoretical integration. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.00974

Dolk, T., Hommel, B., Prinz, W., & Liepelt, R. (2013). The (not so) social Simon effect: A referential coding account. *Journal of Experimental Psychology: Human Perception and Performance*, *39*(5), 1248–1260. https://doi.org/10.1037/a0031031

Driver, J., Davis, G., Ricciardelli, P., Kidd, P., Maxwell, E., & Baron-Cohen, S. (1999). Gaze Perception Triggers Reflexive Visuospatial Orienting. *Visual Cognition*, *6*(5), 509–540. https://doi.org/10.1080/135062899394920

Duane, T. D., & Behrendt, T. (1965). Extrasensory Electroencephalographic Induction between Identical Twins. *Science*, *150*(3694), 367–367. https://doi.org/10.1126/science.150.3694.367

Dunbar, R. I. M. (2003). The Social Brain: Mind, Language, and Society in Evolutionary Perspective. *Annual Review of Anthropology*, *32*(1), 163–181. https://doi.org/10.1146/annurev.anthro.32.061002.093158

Dunham, Y. (2018). Mere Membership. *Trends in Cognitive Sciences*, *22*(9), 780–793. https://doi.org/10.1016/j.tics.2018.06.004

Eimer, M. (1993). Effects of attention and stimulus probability on ERPs in a Go/Nogo task. *Biological Psychology*, *35*(2), 123–138. https://doi.org/10.1016/0301-0511(93)90009-W

Eimer, M. (1996). ERP modulations indicate the selective processing of visual stimuli as a result of transient and sustained spatial attention. *Psychophysiology*, *33*(1), 13–21. https://doi.org/10.1111/j.1469-8986.1996.tb02104.x

Emery, N. J. (2000). The eyes have it: The neuroethology, function and evolution of social gaze. *Neuroscience & Biobehavioral Reviews*, *24*(6), 581–604. https://doi.org/10.1016/S0149-7634(00)00025-7

Erceg-Hurn, D. M., Wilcox, R. R., & Keselman, H. J. (2013). Robust Statistical Estimation. *The Oxford Handbook of Quantitative Methods in Psychology, Vol. 1*. https://doi.org/10.1093/oxfordhb/9780199934874.013.0019

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16*(1), 143–149. https://doi.org/10.3758/BF03203267

Fan, J., Byrne, J., Worden, M. S., Guise, K. G., McCandliss, B. D., Fossella, J., & Posner, M. I. (2007). The Relation of Brain Oscillations to Attentional Networks. *Journal of Neuroscience*, *27*(23), 6197–6206. https://doi.org/10.1523/JNEUROSCI.1833-07.2007

Felleman, D. J., & Van Essen, D. C. (1991). Distributed hierarchical processing in the primate cerebral cortex. *Cerebral Cortex (New York, N.Y.: 1991)*, *1*(1), 1–47. https://doi.org/10.1093/cercor/1.1.1

Field, A. P., & Wilcox, R. R. (2017). Robust statistical methods: A primer for clinical psychology and experimental psychopathology researchers. *Behaviour Research and Therapy*, *98*, 19–38. https://doi.org/10.1016/j.brat.2017.05.013

Fisher, R. J. (1993). Social desirability bias and the validity of indirect questioning. *Journal of Consumer Research*, *20*(2), 303–315. https://doi.org/10.1086/209351

Folstein, J. R., & Van Petten, C. (2007). Influence of cognitive control and mismatch on the N2 component of the ERP: A review. *Psychophysiology*, *0*(0), 070915195953001-??? https://doi.org/10.1111/j.1469-8986.2007.00602.x

Francis, G. (2012). Publication bias and the failure of replication in experimental psychology. *Psychonomic Bulletin & Review*, *19*(6), 975–991. https://doi.org/10.3758/s13423-012-0322-y

Fresco, D. M., Coles, M. E., Heimberg, R. G., Liebowitz, M. R., Hami, S., Stein, M. B., & Goetz, D. (2001). The Liebowitz Social Anxiety Scale: A comparison of the psychometric properties of self-report and clinician-administered formats. Psychological Medicine, 31, 1025–1035. http://dx.doi.org/10.1017/S0033291701004056

Fries, P. (2005). A mechanism for cognitive dynamics: Neuronal communication through neuronal coherence. *Trends in Cognitive Sciences*, *9*(10), 474–480. https://doi.org/10.1016/j.tics.2005.08.011

Fries, P. (2015). Rhythms for Cognition: Communication through Coherence. *Neuron*, *88*(1), 220–235. https://doi.org/10.1016/j.neuron.2015.09.034

Friesen, C. K., & Kingstone, A. (1998). The eyes have it! Reflexive orienting is triggered by nonpredictive gaze. *Psychonomic Bulletin & Review*, *5*(3), 490–495. https://doi.org/10.3758/BF03208827

Friesen, C. K., Ristic, J., & Kingstone, A. (2004). Attentional Effects of Counterpredictive Gaze and Arrow Cues. *Journal of Experimental Psychology: Human Perception and Performance*, *30*(2), 319–329. https://doi.org/10.1037/0096-1523.30.2.319

Frischen, A., Bayliss, A. P., & Tipper, S. P. (2007). Gaze cueing of attention: Visual attention, social cognition, and individual differences. *Psychological Bulletin*, *133*(4), 694–724. https://doi.org/10.1037/0033-2909.133.4.694

Frith, C. D., & Frith, U. (2006). The Neural Basis of Mentalizing. *Neuron*, *50*(4), 531–534. https://doi.org/10.1016/j.neuron.2006.05.001

Frith, U. (2001). Mind blindness and the brain in autism. Neuron 32, 969–979. doi: 10.1016/S0896-6273(01)00552-9

Frith, U., and Frith, C. D. (2010). The social brain: allowing humans to boldly go where no other species has been. Philos. Trans. R. Soc. Lond. B Biol. Sci. 365, 165–175. doi: 10.1098/rstb.2009.0160

Funderud, I., Lindgren, M., Løvstad, M., Endestad, T., Voytek, B., Knight, R. T., & Solbakk, A.-K. (2012). Differential Go/NoGo Activity in Both Contingent Negative Variation and Spectral Power. *PLoS ONE*, *7*(10), e48504. https://doi.org/10.1371/journal.pone.0048504

Gallagher, H. L., Happé, F., Brunswick, N., Fletcher, P. C., Frith, U., & Frith, C. D. (2000). Reading the mind in cartoons and stories: An fMRI study of 'theory of mind' in verbal and nonverbal tasks. *Neuropsychologia*, *38*(1), 11–21. https://doi.org/10.1016/S0028-3932(99)00053-6

Gasser, T., Sroka, L., & Möcks, J. (1986). The Correction of EOG Artifacts by Frequency Dependent and Frequency Independent Methods. *Psychophysiology*, *23*(6), 704–712. https://doi.org/10.1111/j.1469-8986.1986.tb00697.x

Geen, R. G. (1991). Social motivation. *Annual Review of Psychology*, *42*, 377–399. https://doi.org/10.1146/annurev.ps.42.020191.002113

Gilbert, D. T., & Hixon, J. G. (1991). The trouble of thinking: Activation and application of stereotypic beliefs. *Journal of Personality and Social Psychology*, *60*(4), 509–517. https://doi.org/10.1037/0022-3514.60.4.509

Gobel, M. S., Kim, H. S., & Richardson, D. C. (2015). The dual function of social gaze. *Cognition*, *136*, 359–364. https://doi.org/10.1016/j.cognition.2014.11.040

Gobel, M. S., Tufft, M. R. A., & Richardson, D. C. (2018). Social Beliefs and Visual Attention: How the Social Relevance of a Cue Influences Spatial Orienting. *Cognitive Science*, *42*, 161–185. https://doi.org/10.1111/cogs.12529

Gordon, I., Eilbott, J. A., Feldman, R., Pelphrey, K. A., & Vander Wyk, B. C. (2013). Social, reward, and attention brain networks are involved when online bids for joint attention are met with congruent versus incongruent responses. *Social Neuroscience*, *8*(6), 544–554. https://doi.org/10.1080/17470919.2013.832374

Granger, C. W. (1969). Investigating causal relations by econometric models and cross-spectral methods. *Econometrica: Journal of the Econometric Society*, 424-438. https://doi.org/10.2307/1912791

Guagnano, D., Rusconi, E., & Umiltà, C. (2013). Joint (Mis-)Representations: A Reply to Welsh et al. (2013). *Journal of Motor Behavior*, *45*(1), 7–8. https://doi.org/10.1080/00222895.2012.752688

Guagnano, D., Rusconi, E., & Umiltà, C. A. (2010). Sharing a task or sharing space? On the effect of the confederate in action coding in a detection task. *Cognition*, *114*(3), 348–355. https://doi.org/10.1016/j.cognition.2009.10.008

Guerin, B. (1993). *Social facilitation*. Cambridge, UK: Cambridge University Press.

Hagemann, D., & Naumann, E. (2001). The effects of ocular artifacts on (lateralized) broadband power in the EEG. *Clinical Neurophysiology*, *112*(2), 215–231. https://doi.org/10.1016/S1388-2457(00)00541-1

Halgren, M., Ulbert, I., Bastuji, H., Fabó, D., Erőss, L., Rey, M., … Cash, S. S. (2019). The generation and propagation of the human alpha rhythm. *Proceedings of the National Academy of Sciences*, 201913092. https://doi.org/10.1073/pnas.1913092116

Han, S., Fan, S., Chen, L., & Zhuo, Y. (1997). On the different processing of wholes and parts: A psychophysiological analysis. *Journal of Cognitive Neuroscience, 9*(5), 687-698. https://doi.org/10.1162/jocn.1997.9.5.687

Han, S., Liu, W., Yund, E. W., & Woods, D. L. (2000). Interactions between spatial attention and global/local feature selection: an ERP study. *Neuroreport, 11*(12), 2753-2758. https://doi.org/10.1097/00001756-200008210-00029

Handy, T. C., & Mangun, G. R. (2000). Attention and spatial selection: Electrophysiological evidence for modulation by perceptual load. *Perception & Psychophysics*, *62*(1), 175–186. https://doi.org/10.3758/BF03212070

Handy, T. C., Soltani, M., & Mangun, G. R. (2001). Perceptual Load and Visuocortical Processing: Event-Related Potentials Reveal Sensory-Level Selection.

Psychological Science, *12*(3), 213–218. https://doi.org/10.1111/1467-9280.00338

Hari, R., & Kujala, M. V. (2009). Brain Basis of Human Social Interaction: From Concepts to Brain Imaging. *Physiological Reviews*, *89*(2), 453–479. https://doi.org/10.1152/physrev.00041.2007

Hari, R., & Puce, A. (2017). *MEG-EEG Primer*. Oxford University Press.

Hari, R., Henriksson, L., Malinen, S., & Parkkonen, L. (2015). Centrality of Social Interaction in Human Brain Function. *Neuron*, *88*(1), 181–193. https://doi.org/10.1016/j.neuron.2015.09.022

Haroush, K., & Williams, Z. M. (2015). Neuronal Prediction of Opponent's Behavior during Cooperative Social Interchange in Primates. *Cell*, *160*(6), 1233–1245. https://doi.org/10.1016/j.cell.2015.01.045

Harrewijn, A., van der Molen, M. J. W., van Vliet, I. M., Tissier, R. L. M., & Westenberg, P. M. (2018). Behavioral and EEG responses to social evaluation: A two-generation family study on social anxiety. *NeuroImage: Clinical*, *17*, 549–562. https://doi.org/10.1016/j.nicl.2017.11.010

Harter, M. R., Aine, C., & Schroeder, C. (1982). Hemispheric differences in the neural processing of stimulus location and type: Effects of selective attention on visual evoked potentials. *Neuropsychologia*, *20*(4), 421–438. https://doi.org/10.1016/0028-3932(82)90041-0

Hauser, D. J., Ellsworth, P. C., & Gonzalez, R. (2018). Are Manipulation Checks Necessary? *Frontiers in Psychology*, *9*, 998. https://doi.org/10.3389/fpsyg.2018.00998

He, X., Lever, A. G., & Humphreys, G. W. (2011). Interpersonal memory-based guidance of attention is reduced for ingroup members. *Experimental Brain Research*, *211*(3–4), 429–438. https://doi.org/10.1007/s00221-011-2698-8

He, X., Sebanz, N., Sui, J., & Humphreys, G. W. (2014). Individualism-collectivism and interpersonal memory guidance of attention. *Journal of Experimental Social Psychology*, *54*, 102–114. https://doi.org/10.1016/j.jesp.2014.04.010

Heed, T., Habets, B., Sebanz, N., & Knoblich, G. (2010). Others' Actions Reduce Crossmodal Integration in Peripersonal Space. *Current Biology*, *20*(15), 1345–1349. https://doi.org/10.1016/j.cub.2010.05.068

Heinze, H. J., Luck, S. J., Mangun, G. R., & Hillyard, S. A. (1990). Visual event-related potentials index focused attention within bilateral stimulus arrays. I. Evidence for early selection. *Electroencephalography and Clinical Neurophysiology*, *75*(6), 511–527. https://doi.org/10.1016/0013-4694(90)90138-A

Helfrich, R. F., & Knight, R. T. (2016). Oscillatory Dynamics of Prefrontal Cognitive Control. *Trends in Cognitive Sciences*, *20*(12), 916–930. https://doi.org/10.1016/j.tics.2016.09.007

Helfrich, R. F., Huang, M., Wilson, G., & Knight, R. T. (2017). Prefrontal cortex modulates posterior alpha oscillations during top-down guided visual perception. *Proceedings of the National Academy of Sciences*, *114*(35), 9457–9462. https://doi.org/10.1073/pnas.1705965114

Helmreich, R. L. (1978). *Work and Family Orientation Questionnaire: An Objective Instrument to Assess Components of Achievement Motivation and Attitudes Toward Family and Career*. Journal Supplement Abstract Service, American Psychological Association.

Herrmann, C. S., Rach, S., Vosskuhl, J., & Strüber, D. (2014). Time–Frequency Analysis of Event-Related Potentials: A Brief Tutorial. *Brain Topography*, *27*(4), 438–450. https://doi.org/10.1007/s10548-013-0327-5

Hillyard, S. A., & Münte, T. F. (1984). Selective attention to color and location: An analysis with event-related brain potentials. *Perception & Psychophysics*, *36*(2), 185–198. https://doi.org/10.3758/BF03202679

Hillyard, S. A., Vogel, E. K., & Luck, S. J. (1998). *Sensory gain control (amplification) as a mechanism of selective attention: Electro- physiological and neuroimaging evidence*. 14.

Hoehl, S., & Markova, G. (2018). Moving developmental social neuroscience toward a second-person approach. *PLOS Biology*, *16*(12), e3000055. https://doi.org/10.1371/journal.pbio.3000055

Hoehl, S., Michel, C., Reid, V. M., Parise, E., & Striano, T. (2014). Eye contact during live social interaction modulates infants’ oscillatory brain activity. *Social Neuroscience*, *9*(3), 300–308. https://doi.org/10.1080/17470919.2014.884982

Hommel, B. (1993). The role of attention for the Simon effect. *Psychological Research*, *55*(3), 208–222. https://doi.org/10.1007/BF00419608

Hommel, B. (1996). No prevalence of right-left over top-bottom spatial codes. *Perception & Psychophysics*, *58*(1), 102–110. https://doi.org/10.3758/BF03205480

Hommel, B., Colzato, L. S., & van den Wildenberg, W. P. M. (2009). How Social Are Task Representations? *Psychological Science*, *20*(7), 794–798. https://doi.org/10.1111/j.1467-9280.2009.02367.x

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The Theory of Event Coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences*, *24*(5), 849–878. https://doi.org/10.1017/S0140525X01000103

Houston, J., Harris, P., McIntire, S., & Francis, D. (2002). Revising the Competitiveness Index using factor analysis. *Psychological Reports*, *90*(1), 31–34. https://doi.org/10.2466/pr0.2002.90.1.31

Huguet, P., Barbet, I., Belletier, C., Monteil, J.-M., & Fagot, J. (2014). Cognitive control under social influence in baboons. *Journal of Experimental Psychology: General*, *143*(6), 2067–2073. https://doi.org/10.1037/xge0000026

Hunt, P. J., & Hillery, J. M. (1973). Social facilitation in a coaction setting: An examination of the effects over learning trials. *Journal of Experimental Social Psychology*, *9*(6), 563–571. https://doi.org/10.1016/0022-1031(73)90038-3

Iani, C., Anelli, F., Nicoletti, R., Arcuri, L., & Rubichi, S. (2011). The role of group membership on the modulation of joint action. *Experimental Brain Research*, *211*(3–4), 439–445. https://doi.org/10.1007/s00221-011-2651-x

Ishii, R., Canuet, L., Ishihara, T., Aoki, Y., Ikeda, S., Hata, M., … Takeda, M. (2014). Frontal midline theta rhythm and gamma power changes during focused attention on mental calculation: An MEG beamformer analysis. *Frontiers in Human Neuroscience*, *8*. https://doi.org/10.3389/fnhum.2014.00406

Jensen, O., & Mazaheri, A. (2010). Shaping Functional Architecture by Oscillatory Alpha Activity: Gating by Inhibition. *Frontiers in Human Neuroscience*, *4*. https://doi.org/10.3389/fnhum.2010.00186

Jensen, O., Spaak, E., & Zumer, J. M. (2019). Human Brain Oscillations: From Physiological Mechanisms to Analysis and Cognition. In S. Supek & C. J. Aine (Eds.), *Magnetoencephalography* (pp. 1–46). https://doi.org/10.1007/978-3-319-62657-4_17-1

Jodo, E., & Kayama, Y. (1992). *Relation of a negative ERP component to response inhibition in a Go/No-go task*. 6.

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, N.J: Prentice-Hall.

Kamarajan, C., Porjesz, B., Jones, K. A., Choi, K., Chorlian, D. B., Padmanabhapillai, A., … Begleiter, H. (2004). The role of brain oscillations as functional correlates of cognitive systems: A study of frontal inhibitory control in alcoholism. *International Journal of Psychophysiology*, *51*(2), 155–180. https://doi.org/10.1016/j.ijpsycho.2003.09.004

Karau, S. J., & Williams, K. D. (1993). Social Loafing: A Meta-Analytic Review and Theoretical Integration. *Journal of Personality and Social Psychology*, *64*(4), 681–706. http://dx.doi.org/10.1037/0022-3514.65.4.681

Kelly, S. P., Lalor, E. C., Reilly, R. B., & Foxe, J. J. (2006). Increases in Alpha Oscillatory Power Reflect an Active Retinotopic Mechanism for Distracter Suppression During Sustained Visuospatial Attention. *Journal of Neurophysiology*, *95*(6), 3844–3851. https://doi.org/10.1152/jn.01234.2005

Kim, N. Y., & Kastner, S. (2019). A biased competition theory for the developmental cognitive neuroscience of visuo-spatial attention. *Current Opinion in Psychology*, *29*, 219–228. https://doi.org/10.1016/j.copsyc.2019.03.017

Kingstone, A., Kachkovski, G., Vasilyev, D., Kuk, M., & Welsh, T. N. (2019). Mental attribution is not sufficient or necessary to trigger attentional orienting to gaze. *Cognition*, *189*, 35–40. https://doi.org/10.1016/j.cognition.2019.03.010

Klein, R. M. (2000). Inhibition of return. *Trends in Cognitive Sciences*, *4*(4), 138–147. https://doi.org/10.1016/S1364-6613(00)01452-2

Klein, R. M., & Taylor, T. L. (1994). Categories of cognitive inhibition with reference to attention. In *Inhibitory processes in attention, memory, and language* (pp. 113–150). San Diego, CA, US: Academic Press.

Klimesch, W, Doppelmayr, M., Russegger, H., Pachinger, T., & Schwaiger, J. (1998). Induced alpha band power changes in the human EEG and attention. *Neuroscience Letters*, *244*(2), 73–76. https://doi.org/10.1016/S0304-3940(98)00122-0

Klimesch, W., Sauseng, P., & Hanslmayr, S. (2007). EEG alpha oscillations: The inhibition–timing hypothesis. *Brain Research Reviews*, *53*(1), 63–88. https://doi.org/10.1016/j.brainresrev.2006.06.003

Knoblich, G., & Sebanz, N. (2006). The Social Nature of Perception and Action. *Current Directions in Psychological Science*, *15*(3), 99–104. https://doi.org/10.1111/j.0963-7214.2006.00415.x

Knoblich, G., Butterfill, S., & Sebanz, N. (2011). Psychological Research on Joint Action. In *Psychology of Learning and Motivation* (Vol. 54, pp. 59–101). https://doi.org/10.1016/B978-0-12-385527-5.00003-6

Koike, T., Tanabe, H. C., & Sadato, N. (2015). Hyperscanning neuroimaging technique to reveal the “two-in-one” system in social interactions. *Neuroscience Research*, *90*, 25–32. https://doi.org/10.1016/j.neures.2014.11.006

Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology*, *38*(3), 557–577. https://doi.org/10.1017/S0048577201990559

Kornblum, S., Hasbroucq, T., & Osman. (1990). Dimensional Overlap: Cognitive Basis for Stimulus-Response Compatibility— A Model and Taxonomy. *Psychological Review*, *97*(2), 253–270.

Kourtis, D., Knoblich, G., Woźniak, M., & Sebanz, N. (2014). Attention Allocation and Task Representation during Joint Action Planning. *Journal of Cognitive Neuroscience*, *26*(10), 2275–2286. https://doi.org/10.1162/jocn_a_00634

Kramer, R. M., & Brewer, M. B. (1984). Effects of group identity on resource use in a simulated commons dilemma. *Journal of Personality and Social Psychology*, *46*(5), 1044–1057. https://doi.org/10.1037/0022-3514.46.5.1044

Lachat, F., Hugueville, L., Lemaréchal, J.-D., Conty, L., & George, N. (2012). Oscillatory Brain Correlates of Live Joint Attention: A Dual-EEG Study. *Frontiers in Human Neuroscience*, *6*. https://doi.org/10.3389/fnhum.2012.00156

Langton, S. R., Watt, R. J., & Bruce, V. (2000). Do the eyes have it? Cues to the direction of social attention. *Trends in cognitive sciences*, *4*(2), 50-59. https://doi.org/10.1016/S1364-6613(99)01436-9

Larson, M. J., Clayson, P. E., & Clawson, A. (2014). Making sense of all the conflict: A theoretical review and critique of conflict-related ERPs. *International Journal of Psychophysiology*, *93*(3), 283–297. https://doi.org/10.1016/j.ijpsycho.2014.06.007

Latané, B., Williams, K., & Harkins, S. (1979). Many hands make light the work: The causes and consequences of social loafing. *Journal of Personality and Social Psychology*, *37*(6), 822–832. https://doi.org/10.1037/0022-3514.37.6.822

Lavie, N. (2005). Distracted and confused?: Selective attention under load. *Trends in Cognitive Sciences*, *9*(2), 75–82. https://doi.org/10.1016/j.tics.2004.12.004

Lavie, N. (2010). Attention, Distraction, and Cognitive Control Under Load. *Current Directions in Psychological Science*, *19*(3), 143–148. https://doi.org/10.1177/0963721410370295

Lavie, N., & de Fockert, J. W. (2003). Contrasting effects of sensory limits and capacity limits in visual selective attention. *Perception & Psychophysics, 65*(2), 202–212. https://doi.org/10.3758/BF03194795

Lavie, N., Ro, T., & Russell, C. (2003). The Role of Perceptual Load in Processing Distractor Faces. *Psychological Science*, *14*(5), 510–515. https://doi.org/10.1111/1467-9280.03453

Lawrence, M. A. (2016). ez: Easy Analysis and Visualization of Factorial Experiments. R package version 4.4-0. https://CRAN.R-project.org/package=ez

Lee, R. F. (2015). Dual logic and cerebral coordinates for reciprocal interaction in eye contact. *PloS One*, *10*(4), e0121791. https://doi.org/10.1371/journal.pone.0121791

Lee, R. F., Dai, W., & Jones, J. (2012). Decoupled circular-polarized dual-head volume coil pair for studying two interacting human brains with dyadic fMRI. *Magnetic Resonance in Medicine*, *68*(4), 1087–1096. https://doi.org/10.1002/mrm.23313

Lee, Y.-C., Lee, J. D., & Boyle, L. N. (2009). The interaction of cognitive load and attention-directing cues in driving. *Human Factors*, *51*(3), 271–280. https://doi.org/10.1177/0018720809337814

Leong, V., Byrne, E., Clackson, K., Georgieva, S., Lam, S., & Wass, S. (2017). Speaker gaze increases information coupling between infant and adult brains. *Proceedings of the National Academy of Sciences*, *114*(50), 13290–13295. https://doi.org/10.1073/pnas.1702493114

Leyens, J.-P., Rodriguez-Perez, A., Rodriguez-Torres, R., Gaunt, R., Paladino, M.-P., Vaes, J., & Demoulin, S. (2001). Psychological essentialism and the differential attribution of uniquely human emotions to ingroups and outgroups. *European Journal of Social Psychology*, *31*(4), 395–411. https://doi.org/10.1002/ejsp.50

Leys, C., Ley, C., Klein, O., Bernard, P., & Licata, L. (2013). Detecting outliers: Do not use standard deviation around the mean, use absolute deviation around the median. *Journal of Experimental Social Psychology*, *49*(4), 764–766. https://doi.org/10.1016/j.jesp.2013.03.013

Liebowitz, M. R. (1987). Social phobia. Modern Problems of Pharmacopsychiatry, 22, 141–173. http://dx.doi.org/10.1159/000414022

Liu, D., Liu, S., Liu, X., Zhang, C., Li, A., Jin, C., … Zhang, X. (2018). Interactive Brain Activity: Review and Progress on EEG-Based Hyperscanning in Social Interactions. *Frontiers in Psychology*, *9*. https://doi.org/10.3389/fpsyg.2018.01862

Lopes da Silva, F. (2013). EEG and MEG: Relevance to Neuroscience. *Neuron*, *80*(5), 1112–1128. https://doi.org/10.1016/j.neuron.2013.10.017

López-García, D., Sobrado, A., Peñalver, J. M. G., Górriz, J. M., & Ruz, M. (2019). *Multivariate pattern analysis techniques for electroencephalography data to study interference effects* [Preprint]. https://doi.org/10.1101/797415

Lu, C., & Proctor, R. W. (1995). The influence of irrelevant location information on performance: A review of the Simon and spatial Stroop effects. *Psychonomic Bulletin & Review*, *2*(2), 174–207. https://doi.org/10.3758/BF03210959

Luck, S. J. (2014). *An introduction to the event-related potential technique* (Second edition). Cambridge, Massachusetts London, England: The MIT Press.

Luck, S. J., & Gaspelin, N. (2017). How to get statistically significant effects in any ERP experiment (and why you shouldn't): How to get significant effects. *Psychophysiology*, *54*(1), 146–157. https://doi.org/10.1111/psyp.12639

Lupiáñez, J., Klein, R. M., & Bartolomeo, P. (2006). Inhibition of return: Twenty years after. *Cognitive Neuropsychology*, *23*(7), 1003–1014. https://doi.org/10.1080/02643290600588095

Luu, P., Tucker, D. M., & Makeig, S. (2004). Frontal midline theta and the error-related negativity: Neurophysiological mechanisms of action regulation. *Clinical Neurophysiology*, *115*(8), 1821–1835. https://doi.org/10.1016/j.clinph.2004.03.031

Ly, A., Verhagen, J., & Wagenmakers, E.-J. (2016). Harold Jeffreys's default Bayes factor hypothesis tests: Explanation, extension, and application in psychology. *Journal of Mathematical Psychology*, 72, 19–32. doi:10.1016/j.jmp.2015.06.004

MacDonald, K., Schug, M., Chase, E., & Barth, H. (2013). My people, right or wrong? Minimal group membership disrupts preschoolers' selective trust. *Cognitive Development*, *28*(3), 247–259. https://doi.org/10.1016/j.cogdev.2012.11.001

Mangun, G. R., & Hillyard, S. A. (1988). Spatial gradients of visual attention: Behavioral and electrophysiological evidence. *Electroencephalography and Clinical Neurophysiology*, *70*(5), 417–428. https://doi.org/10.1016/0013-4694(88)90019-3

Mangun, G. R., & Hillyard, S. A. (1991). Modulations of sensory-evoked brain potentials indicate changes in perceptual processing during visual-spatial priming. *Journal of Experimental Psychology: Human Perception and Performance, 17*(4), 1057–1074. https://doi.org/10.1037/0096-1523.17.4.1057

Mangun, George R. (1995). Neural mechanisms of visual selective attention. *Psychophysiology*, *32*(1), 4–18. https://doi.org/10.1111/j.1469-8986.1995.tb03400.x

Mangun, George R., & Buck, L. A. (1998). Sustained visual-spatial attention produces costs and benefits in response time and evoked neural activity. *Neuropsychologia*, *36*(3), 189–200. https://doi.org/10.1016/S0028-3932(97)00123-1

Martínez, A., DiRusso, F., Anllo-Vento, L., Sereno, M. I., Buxton, R. B., & Hillyard, S. A. (2001). Putting spatial attention on the map: Timing and localization of stimulus selection processes in striate and extrastriate visual areas. *Vision Research*, *41*(10–11), 1437–1457. https://doi.org/10.1016/S0042-6989(00)00267-4

Mattick, R. P., & Clarke, J. C. (1998). Development and validation of measures of social phobia scrutiny fear and social interaction anxiety. Behaviour Research and Therapy, 36, 455– 470. http://dx.doi.org/10 .1016/S0005-7967(97)10031-6

McClung, J. S., Jentzsch, I., & Reicher, S. D. (2013). Group Membership Affects Spontaneous Mental Representation: Failure to Represent the Out-Group in a Joint Action Task. *PLoS ONE*, *8*(11), e79178. https://doi.org/10.1371/journal.pone.0079178

Melnikoff, D. E., & Bargh, J. A. (2018). The Mythical Number Two. *Trends in Cognitive Sciences*, *22*(4), 280–293. https://doi.org/10.1016/j.tics.2018.02.001

Michel, C., Stets, M., Parise, E., Reid, V. M., Striano, T., & Hoehl, S. (2015). Theta- and alpha-band EEG activity in response to eye gaze cues in early infancy. *NeuroImage*, *118*, 576–583. https://doi.org/10.1016/j.neuroimage.2015.06.042

Milward, S. J., & Carpenter, M. (2018). Joint action and joint attention: Drawing parallels between the literatures. *Social and Personality Psychology Compass*, *12*(4), e12377. https://doi.org/10.1111/spc3.12377

Montague, P. (2002). Hyperscanning: Simultaneous fMRI during Linked Social Interactions. *NeuroImage*, *16*(4), 1159–1164. https://doi.org/10.1006/nimg.2002.1150

Moors, A. (2016). Automaticity: Componential, Causal, and Mechanistic Explanations. *Annual Review of Psychology*, *67*(1), 263–287. https://doi.org/10.1146/annurev-psych-122414-033550

Moors, A., & De Houwer, J. (2006). Automaticity: A Theoretical and Conceptual Analysis. *Psychological Bulletin*, *132*(2), 297–326. https://doi.org/10.1037/0033-2909.132.2.297

Morey, R.D., & Rouder, J. N. (2018). BayesFactor: Computation of Bayes Factors for Common Designs. R package version 0.9.12-4.2. https://CRAN.R-project.org/package=BayesFactor

Mu, Y., Cerritos, C., & Khan, F. (2018). Neural mechanisms underlying interpersonal coordination: A review of hyperscanning research. *Social and Personality Psychology Compass*, *12*(11), e12421. https://doi.org/10.1111/spc3.12421

Mückschel, M., Dippel, G., & Beste, C. (2017). Distinguishing stimulus and response codes in theta oscillations in prefrontal areas during inhibitory control of automated responses: Distinguishing Stimulus and Response Codes in Theta Oscillations. *Human Brain Mapping*, *38*(11), 5681–5690. https://doi.org/10.1002/hbm.23757

Müller, B. C. N., Kühn, S., van Baaren, R. B., Dotsch, R., Brass, M., & Dijksterhuis, A. (2011). Perspective taking eliminates differences in co-representation of out-group members' actions. *Experimental Brain Research*, *211*(3–4), 423–428. https://doi.org/10.1007/s00221-011-2654-7

Mundy, P. (2018). A review of joint attention and social-cognitive brain systems in typical development and autism spectrum disorder. *European Journal of Neuroscience*, *47*(6), 497–514. https://doi.org/10.1111/ejn.13720

Mundy, P., & Newell, L. (2007). Attention, Joint Attention, and Social Cognition. *Current Directions in Psychological Science*, *16*(5), 269–274. https://doi.org/10.1111/j.1467-8721.2007.00518.x

Mundy, P., Sullivan, L., & Mastergeorge, A. M. (2009). A parallel and distributed-processing model of joint attention, social cognition and autism. *Autism Research*, *2*(1), 2–21. https://doi.org/10.1002/aur.61

Murphy, G., Groeger, J. A., & Greene, C. M. (2016). Twenty years of load theory—Where are we now, and where should we go next? *Psychonomic Bulletin & Review*, *23*(5), 1316–1340. https://doi.org/10.3758/s13423-015-0982-5

Neumann, M. F., Mohamed, T. N., & Schweinberger, S. R. (2011). Face and object encoding under perceptual load: ERP evidence. *NeuroImage*, *54*(4), 3021–3027. https://doi.org/10.1016/j.neuroimage.2010.10.075

Nicoletti, R., & Umiltà, C. (1994). Attention shifts produce spatial stimulus codes. *Psychological Research*, *56*(3), 144–150. https://doi.org/10.1007/BF00419701

Nigbur, R., Ivanova, G., & Stürmer, B. (2011). Theta power as a marker for cognitive interference. *Clinical Neurophysiology*, *122*(11), 2185–2194. https://doi.org/10.1016/j.clinph.2011.03.030

Nobre, A. C. (2018). Attention. In J. T. Wixted (Ed.), *Stevens' Handbook of Experimental Psychology and Cognitive Neuroscience* (pp. 1–75). https://doi.org/10.1002/9781119170174.epcn206

Nolte, G., & Marzetti, L. (2019). Methods to Estimate Functional and Effective Brain Connectivity from MEG Data Robust to Artifacts of Volume Conduction. In S. Supek & C. J. Aine (Eds.), *Magnetoencephalography* (pp. 1–26). https://doi.org/10.1007/978-3-319-62657-4_21-1

Nolte, G., Bai, O., Wheaton, L., Mari, Z., Vorbach, S., & Hallett, M. (2004). Identifying true brain interaction from EEG data using the imaginary part of coherency. *Clinical Neurophysiology*, *115*(10), 2292–2307. https://doi.org/10.1016/j.clinph.2004.04.029

Nolte, G., Ziehe, A., Nikulin, V. V., Schlögl, A., Krämer, N., Brismar, T., & Müller, K.-R. (2008). Robustly Estimating the Flow Direction of Information in Complex Physical Systems. *Physical Review Letters*, *100*(23), 234101. https://doi.org/10.1103/PhysRevLett.100.234101

Normand, A., Bouquet, C. A., & Croizet, J.-C. (2014). Does evaluative pressure make you less or more distractible? Role of top-down attentional control over response selection. *Journal of Experimental Psychology: General*, *143*(3), 1097–1111. https://doi.org/10.1037/a0034985

Nummenmaa, L., & Calder, A. J. (2009). Neural mechanisms of social attention. *Trends in Cognitive Sciences*, *13*(3), 135–143. https://doi.org/10.1016/j.tics.2008.12.006

Oostenveld, R., Fries, P., Maris, E., & Schoffelen, J.-M. (2011). FieldTrip: Open Source Software for Advanced Analysis of MEG, EEG, and Invasive

Electrophysiological Data. *Computational Intelligence and Neuroscience*, *2011*, 1–9. https://doi.org/10.1155/2011/156869

Palva, S., & Palva, J. M. (2007). New vistas for α-frequency band oscillations. *Trends in Neurosciences*, *30*(4), 150–158. https://doi.org/10.1016/j.tins.2007.02.001

Pan, F., Wu, X., & Zhang, L. (2017). Is Inhibition of Return Modulated by Involuntary Orienting of Spatial Attention: An ERP Study. *Frontiers in Psychology*, *8*. https://doi.org/10.3389/fpsyg.2017.00113

Pashler, H., Johnston, J. C., & Ruthruff, E. (2001). Attention and Performance. *Annual Review of Psychology*, *52*(1), 629–651. https://doi.org/10.1146/annurev.psych.52.1.629

Pastötter, B., Hanslmayr, S., & T. Bäuml, K.-H. (2010). Conflict processing in the anterior cingulate cortex constrains response priming. *NeuroImage*, *50*(4), 1599–1605. https://doi.org/10.1016/j.neuroimage.2010.01.095

Patten, T. M., Rennie, C. J., Robinson, P. A., & Gong, P. (2012). Human Cortical Traveling Waves: Dynamical Properties and Correlations with Responses. *PLoS ONE*, *7*(6), e38392. https://doi.org/10.1371/journal.pone.0038392

Peirce, J. W. (2007). PsychoPy—Psychophysics software in Python. *Journal of Neuroscience Methods*, *162*(1–2), 8–13. https://doi.org/10.1016/j.jneumeth.2006.11.017

Peirce, J., Gray, J. R., Simpson, S., MacAskill, M., Höchenberger, R., Sogo, H., … Lindeløv, J. K. (2019). PsychoPy2: Experiments in behavior made easy. *Behavior Research Methods*, *51*(1), 195–203. https://doi.org/10.3758/s13428-018-01193-y

Pernet, C. R., Chauveau, N., Gaspar, C., & Rousselet, G. A. (2011). LIMO EEG: A Toolbox for Hierarchical LInear MOdeling of ElectroEncephaloGraphic Data. *Computational Intelligence and Neuroscience*, *2011*, 1–11. https://doi.org/10.1155/2011/831409

Perugini, M., Gallucci, M., & Costantini, G. (2018). A Practical Primer To Power Analysis for Simple Experimental Designs. *International Review of Social Psychology*, *31*(1), 20. http://doi.org/10.5334/irsp.181

Pfefferbaum, A., Ford, J. M., Weller, B. J., & Kopell, B. S. (1985). ERPs to response production and inhibition. *Electroencephalography and Clinical Neurophysiology*, *60*(5), 423–434. https://doi.org/10.1016/0013-4694(85)91017-x

Pfeiffer, U. J., Schilbach, L., Timmermans, B., Kuzmanovic, B., Georgescu, A. L., Bente, G., & Vogeley, K. (2014). Why we interact: On the functional role of the striatum in the subjective experience of social interaction. *NeuroImage*, *101*, 124–137. https://doi.org/10.1016/j.neuroimage.2014.06.061

Pfurtscheller, G. (2001). Functional brain imaging based on ERD/ERS. *Vision Research*, *41*(10–11), 1257–1260. https://doi.org/10.1016/S0042-6989(00)00235-2

Pfurtscheller, G. (2003). Induced Oscillations in the Alpha Band: Functional Meaning. *Epilepsia*, *44*(s12), 2–8. https://doi.org/10.1111/j.0013-9580.2003.12001.x

Plötner, M., Over, H., Carpenter, M., & Tomasello, M. (2015). The effects of collaboration and minimal-group membership on children's prosocial behavior, liking, affiliation, and trust. *Journal of Experimental Child Psychology*, *139*, 161–173. https://doi.org/10.1016/j.jecp.2015.05.008

Polich, J., & Kok, A. (1995). Cognitive and biological determinants of P300: An integrative review. *Biological Psychology*, *41*(2), 103–146. https://doi.org/10.1016/0301-0511(95)05130-9

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*(1), 3–25. https://doi.org/10.1080/00335558008248231

Posner, M. I., Rafal, R. D., Choate, L. S., & Vaughan, J. (1985). Inhibition of return: Neural basis and function. *Cognitive Neuropsychology*, *2*(3), 211–228. https://doi.org/10.1080/02643298508252866

Pylyshyn, Z. W., & Storm, R. W. (1988). Tracking multiple independent targets: Evidence for a parallel tracking mechanism*. *Spatial Vision*, *3*(3), 179–197. https://doi.org/10.1163/156856888X00122

Quax, S. C., Dijkstra, N., van Staveren, M. J., Bosch, S. E., & van Gerven, M. A. (2019). Eye movements explain decodability during perception and cued attention in MEG. *NeuroImage*, *195*, 444-453. https://doi.org/10.1016/j.neuroimage.2019.03.069

Ramsey, R., Darda, K. M., & Downing, P. E. (2019). Automatic imitation remains unaffected under cognitive load. *Journal of Experimental Psychology: Human Perception and Performance*, *45*(5), 601–615. https://doi.org/10.1037/xhp0000632

Ray, W., & Cole, H. (1985). EEG alpha activity reflects attentional demands, and beta activity reflects emotional and cognitive processes. *Science*, *228*(4700), 750. https://doi.org/10.1126/science.3992243

Rayson, H., Bonaiuto, J. J., Ferrari, P. F., Chakrabarti, B., & Murray, L. (2019). Building blocks of joint attention: Early sensitivity to having one's own gaze followed. *Developmental Cognitive Neuroscience*, *37*, 100631. https://doi.org/10.1016/j.dcn.2019.100631

Read, J. C. A. (2015). The place of human psychophysics in modern neuroscience. *Neuroscience*, *296*, 116–129. https://doi.org/10.1016/j.neuroscience.2014.05.036

Redcay, E., Kleiner, M., & Saxe, R. (2012). Look at this: The neural correlates of initiating and responding to bids for joint attention. *Frontiers in Human Neuroscience*, *6*. https://doi.org/10.3389/fnhum.2012.00169

Remington, R., & Pierce, L. (1984). Moving attention: Evidence for time-invariant shifts of visual selective attention. *Perception & Psychophysics*, *35*(4), 393–399. https://doi.org/10.3758/BF03206344

Richardson, D. C., & Gobel, M. S. (2015). Social attention. *The handbook of attention*, 349-367.

Richardson, D. C., Street, C. N. H., Tan, J. Y. M., Kirkham, N. Z., Hoover, M. A., & Ghane Cavanaugh, A. (2012). Joint perception: Gaze and social context. *Frontiers in Human Neuroscience*, *6*. https://doi.org/10.3389/fnhum.2012.00194

Ristic, J., Mottron, L., Friesen, C. K., Iarocci, G., Burack, J. A., & Kingstone, A. (2005). Eyes are special but not for everyone: The case of autism. *Cognitive Brain Research*, *24*(3), 715–718. https://doi.org/10.1016/j.cogbrainres.2005.02.007

Rosinski, R. R., Golinkoff, R. M., & Kukish, K. S. (1975). Automatic semantic processing in a picture-word interference task. *Child Development, 46*(1), 247–253. https://doi.org/10.2307/1128859

Rouder, J. N., Morey, R. D., Speckman, P. L., & Province, J. M. (2012). Default Bayes factors for ANOVA designs. *Journal of Mathematical Psychology*, *56*(5), 356–374. https://doi.org/10.1016/j.jmp.2012.08.001

Rouder, J. N., Speckman, P. L., Sun, D., Morey, R. D., & Iverson, G. (2009). Bayesian t tests for accepting and rejecting the null hypothesis. *Psychonomic Bulletin & Review*, *16*(2), 225–237. https://doi.org/10.3758/PBR.16.2.225

Rousselet, G. A., Pernet, C. R., & Wilcox, R. R. (2019a). *A practical introduction to the bootstrap: A versatile method to make inferences by using data-driven simulations* [Preprint]. PsyArXiv. https://doi.org/10.31234/osf.io/h8ft7

Rousselet, G. A., Pernet, C. R., & Wilcox, R. R. (2019b). *The percentile bootstrap: A teaser with step-by-step instructions in R* [Preprint]. PsyArXiv. https://doi.org/10.31234/osf.io/kxarf

Ruby, P., & Decety, J. (2001). Effect of subjective perspective taking during simulation of action: A PET investigation of agency. *Nature Neuroscience*, *4*(5), 546–550. https://doi.org/10.1038/87510

Ruys, K. I., & Aarts, H. (2010). When competition merges people's behavior: Interdependency activates shared action representations. *Journal of Experimental Social Psychology*, *46*(6), 1130–1133. https://doi.org/10.1016/j.jesp.2010.05.016

Sadaghiani, S., & Kleinschmidt, A. (2016). Brain Networks and α-Oscillations: Structural and Functional Foundations of Cognitive Control. *Trends in Cognitive Sciences*, *20*(11), 805–817. https://doi.org/10.1016/j.tics.2016.09.004

Saunders, D. R., Melcher, D., & van Zoest, W. (2019). No evidence of task co-representation in a joint Stroop task. *Psychological Research*, *83*(5), 852–862. https://doi.org/10.1007/s00426-017-0909-z

Sauseng, Klimesch, W., Stadler, W., Schabus, M., Doppelmayr, M., Hanslmayr, S., … Birbaumer, N. (2005). A shift of visual spatial attention is selectively associated with human EEG alpha activity. *European Journal of Neuroscience*, *22*(11), 2917–2926. https://doi.org/10.1111/j.1460-9568.2005.04482.x

Schilbach, L., Timmermans, B., Reddy, V., Costall, A., Bente, G., Schlicht, T., & Vogeley, K. (2013). Toward a second-person neuroscience. *Behavioral and Brain Sciences*, *36*(04), 393–414. https://doi.org/10.1017/S0140525X12000660

Schilbach, L., Wilms, M., Eickhoff, S. B., Romanzetti, S., Tepest, R., Bente, G., … Vogeley, K. (2010). Minds Made for Sharing: Initiating Joint Attention Recruits Reward-related Neurocircuitry. *Journal of Cognitive Neuroscience*, *22*(12), 2702–2715. https://doi.org/10.1162/jocn.2009.21401

Schneider, D., Lam, R., Bayliss, A. P., & Dux, P. E. (2012). Cognitive Load Disrupts Implicit Theory-of-Mind Processing. *Psychological Science*, *23*(8), 842–847. https://doi.org/10.1177/0956797612439070

Schönbrodt, F. D., & Wagenmakers, E.-J. (2018). Bayes factor design analysis: Planning for compelling evidence. *Psychonomic Bulletin & Review*, *25*(1), 128–142. https://doi.org/10.3758/s13423-017-1230-y

Schuller, A.-M., & Rossion, B. (2001). Spatial attention triggered by eye gaze increases and speeds up early visual activity: *Neuroreport*, *12*(11), 2381–2386. https://doi.org/10.1097/00001756-200108080-00019

Schuller, A.-M., & Rossion, B. (2004). Perception of static eye gaze direction facilitates subsequent early visual processing. *Clinical Neurophysiology*, *115*(5), 1161–1168. https://doi.org/10.1016/j.clinph.2003.12.022

Schuller, A., & Rossion, B. (2005). Spatial attention triggered by eye gaze enhances and speeds up visual processing in upper and lower visual fields beyond early striate visual processing. *Clinical Neurophysiology*, *116*(11), 2565–2576. https://doi.org/10.1016/j.clinph.2005.07.021

Sebanz, N, Bekkering, H., & Knoblich, G. (2006). Joint action: bodies and minds moving together. *Trends in Cognitive Sciences*, *10*(2), 70–76. https://doi.org/10.1016/j.tics.2005.12.009

Sebanz, N., & Knoblich, G. (2009). Prediction in Joint Action: What, When, and Where. *Topics in Cognitive Science*, *1*(2), 353–367. https://doi.org/10.1111/j.1756-8765.2009.01024.x

Sebanz, N., Knoblich, G., & Prinz, W. (2003). Representing others' actions: Just like one's own? *Cognition*, *88*(3), B11–B21. https://doi.org/10.1016/S0010-0277(03)00043-X

Sebanz, N., Knoblich, G., & Prinz, W. (2005). How Two Share a Task: Corepresenting Stimulus-Response Mappings. *Journal of Experimental Psychology: Human Perception and Performance*, *31*(6), 1234–1246. https://doi.org/10.1037/0096-1523.31.6.1234

Sebanz, N., Knoblich, G., Prinz, W., & Wascher, E. (2006). Twin Peaks: An ERP Study of Action Planning and Control in Coacting Individuals. *Journal of Cognitive Neuroscience*, *18*(5), 859–870. https://doi.org/10.1162/jocn.2006.18.5.859

Sebanz, N., Knoblich, G., Stumpf, L., & Prinz, W. (2005). Far from action-blind: Representation of others' actions in individuals with Autism. Cognitive Neuropsychology, 22(3-4), 433–454. doi:10.1080/02643290442000121

Sellaro, R., Treccani, B., & Cubelli, R. (2018). When task sharing reduces interference: Evidence for division-of-labour in Stroop-like tasks. *Psychological Research*. https://doi.org/10.1007/s00426-018-1044-1

Senju, A., Southgate, V., White, S., & Frith, U. (2009). Mindblind Eyes: An Absence of Spontaneous Theory of Mind in Asperger Syndrome. Science, 325(5942), 883–885. doi:10.1126/science.1176170

Shahbazi, F., Ewald, A., Ziehe, A., & Nolte, G. (2010). Constructing surrogate data to control for artifacts of volume conduction for functional connectivity measures. In *17th International Conference on Biomagnetism Advances in Biomagnetism–Biomag2010* (pp. 207-210). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-12197-5_46

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological Review*, *84*(2), 127–190. https://doi.org/10.1037/0033-295X.84.2.127

Shteynberg, G. (2010). A silent emergence of culture: The social tuning effect. *Journal of Personality and Social Psychology*, *99*(4), 683–689. https://doi.org/10.1037/a0019573

Shteynberg, G. (2014). A social host in the machine? The case of group attention. *Journal of Applied Research in Memory and Cognition*, *3*(4), 307–311. https://doi.org/10.1016/j.jarmac.2014.05.005

Shteynberg, G. (2015). Shared Attention. *Perspectives on Psychological Science*, *10*(5), 579–590. https://doi.org/10.1177/1745691615589104

Shteynberg, G. (2018). A collective perspective: Shared attention and the mind. *Current Opinion in Psychology*, *23*, 93–97. https://doi.org/10.1016/j.copsyc.2017.12.007

Shteynberg, G., & Apfelbaum, E. P. (2013). The Power of Shared Experience: Simultaneous Observation With Similar Others Facilitates Social Learning. *Social Psychological and Personality Science*, *4*(6), 738–744. https://doi.org/10.1177/1948550613479807

Shteynberg, G., & Galinsky, A. D. (2011). Implicit coordination: Sharing goals with similar others intensifies goal pursuit. *Journal of Experimental Social Psychology*, *47*(6), 1291–1294. https://doi.org/10.1016/j.jesp.2011.04.012

Shteynberg, G., Hirsh, J. B., Apfelbaum, E. P., Larsen, J. T., Galinsky, A. D., & Roese, N. J. (2014). Feeling more together: Group attention intensifies emotion. *Emotion*, *14*(6), 1102–1114. https://doi.org/10.1037/a0037697 e thesis – this is particul

Shteynberg, G., Hirsh, J. B., Galinsky, A. D., & Knight, A. P. (2014). Shared attention increases mood infusion. *Journal of Experimental Psychology: General*, *143*(1), 123–130. https://doi.org/10.1037/a0031549

Siegel, M., Donner, T. H., & Engel, A. K. (2012). Spectral fingerprints of large-scale neuronal interactions. *Nature Reviews Neuroscience*, *13*(2), 121–134. https://doi.org/10.1038/nrn3137

Simon, J. R., & Rudell, A. P. (1967). Auditory S-R compatibility: The effect of an irrelevant cue on information processing. *Journal of Applied Psychology*, *51*(3), 300–304. https://doi.org/10.1037/h0020586

Singelis, T. M., Triandis, H. C., Bhawuk, D. P. S., & Gelfand, M. J. (1995). Horizontal and Vertical Dimensions of Individualism and Collectivism: A Theoretical and Measurement Refinement. *Cross-Cultural Research*, *29*(3), 240–275. https://doi.org/10.1177/106939719502900302

Siposova, B., & Carpenter, M. (2019). A new look at joint attention and common knowledge. *Cognition*, *189*, 260–274. https://doi.org/10.1016/j.cognition.2019.03.019

Skorich, D. P., Gash, T. B., Stalker, K. L., Zheng, L., & Haslam, S. A. (2017). Exploring the Cognitive Foundations of the Shared Attention Mechanism: Evidence for a Relationship Between Self-Categorization and Shared Attention Across the Autism Spectrum. Journal of Autism and Developmental Disorders, 47(5), 1341–1353. doi:10.1007/s10803-017-3049-9

Slessor, G., Finnerty, A., Papp, J., Smith, D. T., & Martin, D. (2019). Gaze-cueing and endogenous attention operate in parallel. *Acta Psychologica*, *192*, 172–180. https://doi.org/10.1016/j.actpsy.2018.11.006

Stephan, W. G., & Stephan, C. W. (1985). Intergroup anxiety. *Journal of Social Issues*, *41*(3), 157–175. https://doi.org/10.1111/j.1540-4560.1985.tb01134.x

Stürmer, S., Snyder, M., Kropp, A., & Siem, B. (2006). Empathy-Motivated Helping: The Moderating Role of Group Membership. *Personality and Social Psychology Bulletin*, *32*(7), 943–956. https://doi.org/10.1177/0146167206287363

Szymanski, C., Pesquita, A., Brennan, A. A., Perdikis, D., Enns, J. T., Brick, T. R., … Lindenberger, U. (2017). Teams on the same wavelength perform better: Inter-brain phase synchronization constitutes a neural substrate for social facilitation. *NeuroImage*, *152*, 425–436. https://doi.org/10.1016/j.neuroimage.2017.03.013

Tajfel, H., Billig, M. G., Bundy, R. P., & Flament, C. (1971). Social categorization and intergroup behaviour. *European Journal of Social Psychology*, *1*(2), 149–178. https://doi.org/10.1002/ejsp.2420010202

Thoma, V., & Lavie, N. (2013). Perceptual load effects on processing distractor faces indicate face-specific capacity limits. *Visual Cognition*, *21*(8), 1053–1076. https://doi.org/10.1080/13506285.2013.853717

Thut, G. (2006). -Band Electroencephalographic Activity over Occipital Cortex Indexes Visuospatial Attention Bias and Predicts Visual Target Detection. *Journal of Neuroscience*, *26*(37), 9494–9502. https://doi.org/10.1523/JNEUROSCI.0875-06.2006

Tipper, C. M., Handy, T. C., Giesbrecht, B., & Kingstone, A. (2008). Brain Responses to Biological Relevance. *Journal of Cognitive Neuroscience*, *20*(5), 879–891. https://doi.org/10.1162/jocn.2008.20510

Tomasello, M., Carpenter, M., Call, J., Behne, T., & Moll, H. (2005). Understanding and sharing intentions: The origins of cultural cognition. *Behavioral and Brain Sciences*, *28*(05). https://doi.org/10.1017/S0140525X05000129

Tomasello, M., Melis, A. P., Tennie, C., Wyman, E., & Herrmann, E. (2012). Two Key Steps in the Evolution of Human Cooperation: The Interdependence Hypothesis. *Current Anthropology*, *53*(6), 673–692. https://doi.org/10.1086/668207

Triandis, H. C. (1995). *New directions in social psychology. Individualism & collectivism.* Westview Press.

Triandis, Harry C., & Gelfand, M. J. (1998). Converging measurement of horizontal and vertical individualism and collectivism. *Journal of Personality and Social Psychology*, *74*(1), 118–128. https://doi.org/10.1037/0022-3514.74.1.118

Triplett, N. (1898). The dynamogenic factors in pacemaking and competition. *The American Journal of Psychology, 9*(4), 507– 533. https://doi.org/10.2307/1412188

Trujillo, L. T., & Allen, J. J. B. (2007). Theta EEG dynamics of the error-related negativity. *Clinical Neurophysiology*, *118*(3), 645–668. https://doi.org/10.1016/j.clinph.2006.11.009

Tsai, C.-C., Kuo, W.-J., Hung, D. L., & Tzeng, O. J. L. (2008). Action Co-representation is Tuned to Other Humans. *Journal of Cognitive Neuroscience*, *20*(11), 2015–2024. https://doi.org/10.1162/jocn.2008.20144

Tufft, M., & Richardson, D. C. (2019). Social Offloading: How Working Together Removes Semantic Interference Effects. Manuscript submitted for publication.

Tufft, M., Gobel, M. S., & Richardson, D. C. (2015). Social Eye Cue: How Knowledge Of Another Person's Attention Changes Your Own. In *CogSci*.

van den Heuvel, M. P., & Hulshoff Pol, H. E. (2010). Exploring the brain network: A review on resting-state fMRI functional connectivity. *European Neuropsychopharmacology*, *20*(8), 519–534. https://doi.org/10.1016/j.euroneuro.2010.03.008

Van Overwalle, F. (2009). Social cognition and the brain: A meta-analysis. *Human Brain Mapping*, *30*(3), 829–858. https://doi.org/10.1002/hbm.20547

Van Veen, V., & Carter, C. S. (2002). The anterior cingulate as a conflict monitor: FMRI and ERP studies. *Physiology & Behavior*, *77*(4–5), 477–482. https://doi.org/10.1016/S0031-9384(02)00930-7

Vassena, E., Holroyd, C. B., & Alexander, W. H. (2017). Computational Models of Anterior Cingulate Cortex: At the Crossroads between Prediction and Effort. *Frontiers in Neuroscience*, *11*, 316. https://doi.org/10.3389/fnins.2017.00316

Vogel, E. K., & Luck, S. J. (2000). The visual N1 component as an index of a discrimination process. *Psychophysiology, 37*(2), 190–203. https://doi.org/10.1017/S0048577200981265

von Stein, A., & Sarnthein, J. (2000). Different frequencies for different scales of cortical integration: From local gamma to long range alpha/theta synchronization. *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology*, *38*(3), 301–313. https://doi.org/10.1016/s0167-8760(00)00172-0

von Stein, A., Chiang, C., & Konig, P. (2000). Top-down processing mediated by interareal synchronization. *Proceedings of the National Academy of Sciences*, *97*(26), 14748–14753. https://doi.org/10.1073/pnas.97.26.14748

Vossel, S., Geng, J. J., & Fink, G. R. (2014). Dorsal and Ventral Attention Systems: Distinct Neural Circuits but Collaborative Roles. *The Neuroscientist*, *20*(2), 150–159. https://doi.org/10.1177/1073858413494269

Vuillier, L., Bryce, D., Szücs, D., & Whitebread, D. (2016). The Maturation of Interference Suppression and Response Inhibition: ERP Analysis of a Cued Go/Nogo Task. *PLOS ONE*, *11*(11), e0165697. https://doi.org/10.1371/journal.pone.0165697

Wagenmakers, E.-J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Love, J., Selker, R., Gronau, Q. F., Šmíra, M., Epskamp, S., Matzke, D., Rouder, J. N., & Morey, R. D. (2018). Bayesian inference for psychology. Part I: Theoretical advantages and practical ramifications. *Psychonomic Bulletin & Review*, *25*(1), 35–57. https://doi.org/10.3758/s13423-017-1343-3

Wahlsten, D. (1991). Sample size to detect a planned contrast and a one degree-of-freedom interaction effect. *Psychological Bulletin, 110*(3), 587–595. https://doi.org/10.1037/0033-2909.110.3.587

Wahn, B., Keshava, A., Sinnett, S., Kingstone, A., & König, P. (2017). Audiovisual integration is affected by performing a task jointly. In *CogSci*. 1296–1301.

Wahn, B., Kingstone, A., & König, P. (2017). Two Trackers Are Better than One: Information about the Co-actor's Actions and Performance Scores Contribute to the Collective Benefit in a Joint Visuospatial Task. *Frontiers in Psychology*, *8*, 669. https://doi.org/10.3389/fpsyg.2017.00669

Walter, W. G. (1936). The location of cerebral tumours by electro-encephalography. *The Lancet*, *228*(5893), 305–308. https://doi.org/10.1016/S0140-6736(01)05173-X

Wang, M.-Y., Luan, P., Zhang, J., Xiang, Y.-T., Niu, H., & Yuan, Z. (2018). Concurrent mapping of brain activation from multiple subjects during social interaction by hyperscanning: A mini-review. *Quantitative Imaging in Medicine and Surgery*, *8*(8), 819–837. https://doi.org/10.21037/qims.2018.09.07

Wang, X.-J. (2010). Neurophysiological and Computational Principles of Cortical Rhythms in Cognition. *Physiological Reviews*, *90*(3), 1195–1268. https://doi.org/10.1152/physrev.00035.2008

Wass, S. V., Noreika, V., Georgieva, S., Clackson, K., Brightman, L., Nutbrown, R., … Leong, V. (2018). Parental neural responsivity to infants' visual attention: How mature brains influence immature brains during social interaction. *PLOS Biology*, *16*(12), e2006328. https://doi.org/10.1371/journal.pbio.2006328

Wei, G., Rushby, J. A., & De Blasio, F. M. (2019). Neurophysiological correlates of visuospatial attention and the social dynamics of gaze processing. *Cognitive,* *Affective, & Behavioral Neuroscience*. https://doi.org/10.3758/s13415-019-00728-w

Welsh, T. N., Elliott, D., Anson, J. G., Dhillon, V., Weeks, D. J., Lyons, J. L., & Chua, R. (2005). Does Joe influence Fred's action? *Neuroscience Letters*, *385*(2), 99–104. https://doi.org/10.1016/j.neulet.2005.05.013

Welsh, T. N., Higgins, L., Ray, M., & Weeks, D. J. (2007). Seeing vs. believing: Is believing sufficient to activate the processes of response co-representation? *Human Movement Science*, *26*(6), 853–866. https://doi.org/10.1016/j.humov.2007.06.003

Welsh, T. N., Kiernan, D., Neyedli, H. F., Ray, M., Pratt, J., Potruff, A., & Weeks, D. J. (2013). Joint Simon Effects in Extrapersonal Space. *Journal of Motor Behavior*, *45*(1), 1–5. https://doi.org/10.1080/00222895.2012.746635

Welsh, T. N., Lyons, J., Weeks, D. J., Anson, J. G., Chua, R., Mendoza, J., & Elliott, D. (2007). Within- and between-nervous-system inhibition of return: Observation is as good as performance. *Psychonomic Bulletin & Review*, *14*(5), 950–956. https://doi.org/10.3758/BF03194127

Wiese, E., Wykowska, A., Zwickel, J., & Müller, H. J. (2012). I See What You Mean: How Attentional Selection Is Shaped by Ascribing Intentions to Others. *PLoS ONE*, *7*(9), e45391. https://doi.org/10.1371/journal.pone.0045391

Wilcox, R. R. (2012). *Introduction to robust estimation and hypothesis testing* (3rd ed). Amsterdam ; Boston: Academic Press.

Wilcox, R. R., & Rousselet, G. A. (2018). A Guide to Robust Statistical Methods in Neuroscience: A Guide to Robust Statistical Methods. In C. R. Gerfen, A. Holmes, D. Sibley, P. Skolnick, & S. Wray (Eds.), *Current Protocols in Neuroscience* (pp. 8.42.1-8.42.30). John Wiley & Sons, Inc. https://doi.org/10.1002/cpns.41

Wilcox, R.R., & Schönbrodt, F.D. (2014). The WRS package for robust statistics in R (version 0.24). Retrieved from http://r-forge.r-project.org/projects/wrs/

Williams, J. H. G., Waiter, G. D., Perra, O., Perrett, D. I., & Whiten, A. (2005). An fMRI study of joint attention experience. *NeuroImage*, *25*(1), 133–140. https://doi.org/10.1016/j.neuroimage.2004.10.047

Wolf, W., Launay, J., & Dunbar, R. I. M. (2016). Joint attention, shared goals, and social bonding. *British Journal of Psychology*, *107*(2), 322–337. https://doi.org/10.1111/bjop.12144

Worden, M. S., Foxe, J. J., Wang, N., & Simpson, G. V. (2000). Anticipatory Biasing of Visuospatial Attention Indexed by Retinotopically Specific α-Bank Electroencephalography Increases over Occipital Cortex. *The Journal of*

Neuroscience, *20*(6), RC63–RC63. https://doi.org/10.1523/JNEUROSCI.20-06-j0002.2000

Wykowska, A., Wiese, E., Prosser, A., & Müller, H. J. (2014). Beliefs about the Minds of Others Influence How We Process Sensory Information. *PLoS ONE*, *9*(4), e94339. https://doi.org/10.1371/journal.pone.0094339

Xu, S., Zhang, S., & Geng, H. (2011). Gaze-induced joint attention persists under high perceptual load and does not depend on awareness. *Vision Research*, *51*(18), 2048–2056. https://doi.org/10.1016/j.visres.2011.07.023

Zajonc, R. B. (1965). Social facilitation. *Science*, *149*(3681), 269–274. https://doi.org/10.1126/science.149.3681.269

Zhang, D. (2018). Computational EEG Analysis for Hyperscanning and Social Neuroscience. In C.-H. Im (Ed.), *Computational EEG Analysis* (pp. 215–228). https://doi.org/10.1007/978-981-13-0908-3_10

Zhou, B., Zhang, J. X., Tan, L. H., & Han, S. (2004). Spatial congruence in working memory: an ERP study. *NeuroReport*, *15*(18), 2795-2799.

Appendix A (1): Individualism-Collectivism scale (IND-COL)

(Singelis, Triandis, Bhawuk, & Gelfand, 1995)

Participant No. ________ sitting on left / right (circle one answer), of pair No._____

Please answer the 32 questions below by putting a number from 1 to 7 for each question. The number ranges from *strongly disagree* (1) to *strongly agree* (7).

1 2 3 4 5 6 7

Strongly disagree ——————————→ *Strongly agree*

1. It annoys me when other people perform better than I do. ( )
2. I enjoy working in situations involving competition with others. ( )
3. I usually sacrifice my self-interest for the benefit of my group. ( )
4. When I succeed, it is usually because of my abilities. ( )
5. Competition is the law of nature. ( )
6. Some people emphasize winning; I'm not one of them. ( )
7. When another person does better than I do, I get tense and aroused. ( )
8. I would do what would please my family, even if I detested that activity. ( )
9. Children should feel honoured if their parents receive a distinguished award. ( )
10. What happens to me is my own doing. ( )
11. I enjoy being unique and different from others in many ways. ( )
12. My happiness depends very much on the happiness of those around me. ( )
13. Winning is everything. ( )
14. It is important to maintain harmony within my group. ( )
15. I am a unique individual. ( )
16. Children should be taught to place duty before pleasure. ( )
17. If a co-worker gets a prize, I would feel proud. ( )
18. I like my privacy. ( )
19. I often do "my own thing". ( )
20. I prefer to be direct and forthright when discussing with people. ( )
21. It is important that I do my job better than others. ( )
22. One should live one's life independently of others. ( )

23. Without competition, it is not possible to have a good society. ( )

24. I hate to disagree with others in my group. ( )

25. I feel good when I cooperate with others. ( )

26. The well-being of my co-workers is important to me. ( )

27. To me, pleasure is spending time with others. ( )

28. If a relative were in financial difficulty, I would help within my means. ( )

29. I like sharing little things with my neighbours. ( )

30. We should keep our aging parents with us at home. ( )

31. I would sacrifice an activity that I enjoy very much if my family did not approve of it. ( )

32. Before taking a major trip, I consult with most members of my family and many friends. ( )

Appendix A (2): Autism-spectrum Quotient (AQ)

(Baron-Cohen et al., 2001)

Participant No. _____________.

Sitting at left / right (please circle one item), of pair No. _______

Below is a list of statements. Please read each statement very carefully and rate how strongly you agree or disagree with it by circling your answer.

1. I prefer to do things with others rather than on my own.	definitely agree	slightly agree	slightly disagree	definitely disagree
2. I prefer to do things the same way over and over again.	definitely agree	slightly agree	slightly disagree	definitely disagree
3. If I try to imagine something, I find it very easy to create a picture in my mind.	definitely agree	slightly agree	slightly disagree	definitely disagree
4. I frequently get so strongly absorbed in one thing that I lose sight of other things.	definitely agree	slightly agree	slightly disagree	definitely disagree
5. I often notice small sounds when others do not.	definitely agree	slightly agree	slightly disagree	definitely disagree
6. I usually notice car number plates or similar strings of information.	definitely agree	slightly agree	slightly disagree	definitely disagree
7. Other people frequently tell me that what I've said is impolite, even though I think it is polite.	definitely agree	slightly agree	slightly disagree	definitely disagree
8. When I'm reading a story, I can easily imagine what the characters might look like.	definitely agree	slightly agree	slightly disagree	definitely disagree
9. I am fascinated by dates.	definitely agree	slightly agree	slightly disagree	definitely disagree
10. In a social group, I can easily keep track of several different people's conversations.	definitely agree	slightly agree	slightly disagree	definitely disagree
11. I find social situations easy.	definitely agree	slightly agree	slightly disagree	definitely disagree
12. I tend to notice details that others do not.	definitely agree	slightly agree	slightly disagree	definitely disagree
13. I would rather go to a library than a party.	definitely agree	slightly agree	slightly disagree	definitely disagree
14. I find making up stories easy.	definitely agree	slightly agree	slightly disagree	definitely disagree
15. I find myself drawn more strongly to	definitely	slightly	slightly	definitely

people than to things.	agree	agree	disagree	disagree
16. I tend to have very strong interests which I get upset about if I can't pursue.	definitely agree	slightly agree	slightly disagree	definitely disagree
17. I enjoy social chit-chat.	definitely agree	slightly agree	slightly disagree	definitely disagree
18. When I talk, it isn't always easy for others to get a word in edgeways.	definitely agree	slightly agree	slightly disagree	definitely disagree
19. I am fascinated by numbers.	definitely agree	slightly agree	slightly disagree	definitely disagree
20. When I'm reading a story, I find it difficult to work out the characters' intentions.	definitely agree	slightly agree	slightly disagree	definitely disagree
21. I don't particularly enjoy reading fiction.	definitely agree	slightly agree	slightly disagree	definitely disagree
22. I find it hard to make new friends.	definitely agree	slightly agree	slightly disagree	definitely disagree
23. I notice patterns in things all the time.	definitely agree	slightly agree	slightly disagree	definitely disagree
24. I would rather go to the theatre than a museum.	definitely agree	slightly agree	slightly disagree	definitely disagree
25. It does not upset me if my daily routine is disturbed.	definitely agree	slightly agree	slightly disagree	definitely disagree
26. I frequently find that I don't know how to keep a conversation going.	definitely agree	slightly agree	slightly disagree	definitely disagree
27. I find it easy to "read between the lines" when someone is talking to me.	definitely agree	slightly agree	slightly disagree	definitely disagree
28. I usually concentrate more on the whole picture, rather than the small details.	definitely agree	slightly agree	slightly disagree	definitely disagree
29. I am not very good at remembering phone numbers.	definitely agree	slightly agree	slightly disagree	definitely disagree
30. I don't usually notice small changes in a situation, or a person's appearance.	definitely agree	slightly agree	slightly disagree	definitely disagree
31. I know how to tell if someone listening to me is getting bored.	definitely agree	slightly agree	slightly disagree	definitely disagree
32. I find it easy to do more than one thing at once.	definitely agree	slightly agree	slightly disagree	definitely disagree
33. When I talk on the phone, I'm not sure when it's my turn to speak.	definitely agree	slightly agree	slightly disagree	definitely disagree
34. I enjoy doing things spontaneously.	definitely agree	slightly agree	slightly disagree	definitely disagree
35. I am often the last to understand the point of a joke.	definitely agree	slightly agree	slightly disagree	definitely disagree
36. I find it easy to work out what someone is thinking or feeling just by looking at their face.	definitely agree	slightly agree	slightly disagree	definitely disagree
37. If there is an interruption, I can switch back to what I was doing very quickly.	definitely agree	slightly agree	slightly disagree	definitely disagree

38. I am good at social chit-chat.	definitely agree	slightly agree	slightly disagree	definitely disagree
39. People often tell me that I keep going on and on about the same thing.	definitely agree	slightly agree	slightly disagree	definitely disagree
40. When I was young, I used to enjoy playing games involving pretending with other children.	definitely agree	slightly agree	slightly disagree	definitely disagree
41. I like to collect information about categories of things (e.g. types of car, types of bird, types of train, types of plant, etc.).	definitely agree	slightly agree	slightly disagree	definitely disagree
42. I find it difficult to imagine what it would be like to be someone else.	definitely agree	slightly agree	slightly disagree	definitely disagree
43. I like to plan any activities I participate in carefully.	definitely agree	slightly agree	slightly disagree	definitely disagree
44. I enjoy social occasions.	definitely agree	slightly agree	slightly disagree	definitely disagree
45. I find it difficult to work out people's intentions.	definitely agree	slightly agree	slightly disagree	definitely disagree
46. New situations make me anxious.	definitely agree	slightly agree	slightly disagree	definitely disagree
47. I enjoy meeting new people.	definitely agree	slightly agree	slightly disagree	definitely disagree
48. I am a good diplomat.	definitely agree	slightly agree	slightly disagree	definitely disagree
49. I am not very good at remembering people's date of birth.	definitely agree	slightly agree	slightly disagree	definitely disagree
50. I find it very easy to play games with children that involve pretending.	definitely agree	slightly agree	slightly disagree	definitely disagree

Appendix A (3): State-Trait Anxiety Inventory (STAI)

(Spielberger, 2012)

Participant No. _____________.
Sitting at left / right (please circle one item), of pair No. _______

Form Y-1

*A number of statements which people have used to describe themselves are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you feel **right now**, that is, at this very moment. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your **present** feelings best.*

1	2	3	4
Not at all	**Somewhat**	**Moderately**	**Very Much So**

1.	I feel calm	1	2	3	4
2.	I feel secure	1	2	3	4
3.	I feel tense	1	2	3	4
4.	I feel strained	1	2	3	4
5.	I feel at ease	1	2	3	4
6.	I feel upset	1	2	3	4
7.	I am presently worrying over possible misfortunes	1	2	3	4
8.	I feel satisfied	1	2	3	4
9.	I feel frightened	1	2	3	4
10.	I feel uncomfortable	1	2	3	4
11.	I feel self confident	1	2	3	4
12.	I feel nervous	1	2	3	4
13.	I feel jittery	1	2	3	4
14.	I feel indecisive	1	2	3	4
15.	I am relaxed	1	2	3	4
16.	I feel content	1	2	3	4
17.	I am worried	1	2	3	4
18.	I feel confused	1	2	3	4
19.	I feel steady	1	2	3	4
20.	I feel pleasant	1	2	3	4

Form Y-2

*A number of statements which people have used to describe themselves are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you **generally** feel. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe how you **generally** feel.*

1	2	3	4
Almost Never	**Sometimes**	**Often**	**Almost Always**

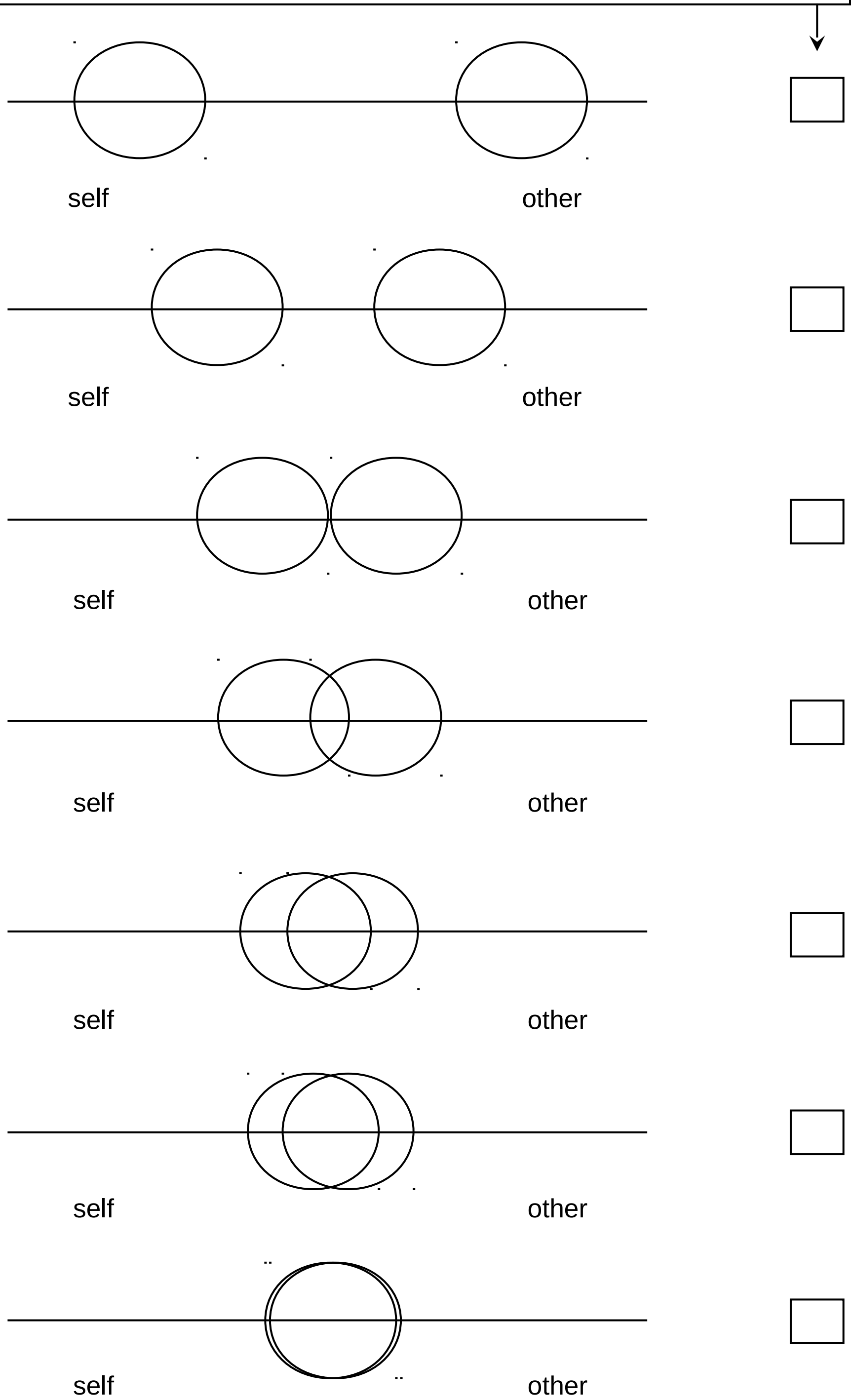
21. I feel pleasant	1	2	3	4
22. I feel nervous and restless	1	2	3	4
23. I feel satisfied with myself	1	2	3	4
24. I wish I could be as happy as others seem to be	1	2	3	4
25. I feel like a failure	1	2	3	4
26. I feel rested	1	2	3	4
27. I am “calm, cool, and collected”	1	2	3	4
28. I feel that difficulties are piling up so that I cannot overcome them	1	2	3	4
29. I worry too much over something that really doesn’t matter	1	2	3	4
30. I am happy	1	2	3	4
31. I have disturbing thoughts	1	2	3	4
32. I lack self-confidence	1	2	3	4
33. I feel secure	1	2	3	4
34. I make decisions easily	1	2	3	4
35. I feel inadequate	1	2	3	4
36. I am content	1	2	3	4
37. Some unimportant thought runs through my mind and bothers me	1	2	3	4
38. I take disappointment so keenly that I can’t put them out of my mind	1	2	3	4
39. I am a steady person	1	2	3	4
40. I get in a state of tension or turmoil as I think over my recent concerns and interests	1	2	3	4

Appendix A (4): Inclusion of the Other in the Self scale (IOS)

(Aron, Aron, & Smollan, 1992)

Participant No. ________ sitting on <u>left / right</u> (circle one answer), of pair No.______
Colour preference: ______________

Pictures below describe the closeness between you (self) and your testing partner (other).
Please tick one picture which best describes your relationship.



Appendix A (5): Trust

Participant No. ________ sitting on left / right (circle one answer), of pair No.______
Colour preference: _______________

Please answer the question below by putting a number from 1 to 7. The number ranges from *strongly disagree* (1) to *strongly agree* (7).

1 2 3 4 5 6 7

Totally no trust ——————————→ *Full trust*

Question:

During the test, to what extent did you trust your testing partner's ability to perform well in this study?

Answer: ________________

Appendix A (6): Combined competitiveness questionnaire

(He, Sebanz, Sui, & Humphreys, 2014)

Participant No. ________ sitting on left / right (circle one answer), of pair No.______

Colour preference: _______________

The questionnaire is anonymous, and there are no right or wrong answers. We want to know to what extent each question applies. The number ranges from 1: strongly disagree to 5: strongly agree. Put a number after each sentence to show your opinion.

Strongly disagree 1 2 3 4 5 Strongly agree

1. I like competition.
2. I am a competitive individual.
3. I enjoy competing against an opponent.
4. I don't like competing against other people.
5. I get satisfaction from competing with others.
6. I find competitive situations unpleasant.
7. I dread competing against other people.
8. I try to avoid competing with others.
9. I often try to outperform others.
10. I try to avoid arguments.
11. I will do almost anything to avoid an argument.
12. I often remain quiet rather than risk hurting another person.
13. I don't enjoy challenging others even when I think they are wrong.
14. In general, I will go along with the group rather than create conflict.
15. I enjoy working in situations involving competition with others.
16. It is important to me to perform better than others on a task.
17. I feel that winning is important in both work and games.
18. It annoys me when other people perform better than I do.
19. I try harder when I'm in competition with other people.
20. I feel competitive in relation to other participants in this study.