Running Head: SUPERIOR FACE RECOGNITION

An In-depth Cognitive Examination of Individuals with Superior Face Recognition Skills

Anna K Bobak[1], Rachel J Bennetts[1], Benjamin A Parris[1], Ashok Jansari[2] & Sarah Bate[1]

[1]Department of Psychology, Bournemouth University, UK;

[2]Department of Psychology, Goldsmiths, University of London, UK.

Address for correspondence:

Anna Bobak
Department of Psychology
Faculty of Science and Technology
Poole House
Bournemouth University
Fern Barrow
Poole
BH12 5BB
United Kingdom

Telephone: +44 (0) 1202 961 532
Fax: +44 (0) 1202 965314
Email: abobak@bournemouth.ac.uk

Abstract

Previous work has reported the existence of “super-recognisers” (SRs), or individuals with extraordinary face recognition skills. However, the precise underpinnings of this ability have not yet been investigated. In this paper we examine (a) the face-specificity of super recognition, (b) perception of facial identity in SRs, (c) whether SRs present with enhancements in holistic processing and (d) the consistency of these findings across different SRs. A detailed neuropsychological investigation into six SRs indicated domain-specificity in three participants, with some evidence of enhanced generalised visuo-cognitive or socio-emotional processes in the remaining individuals. While superior face-processing skills were restricted to face memory in three of the SRs, enhancements to facial identity perception were observed in the others. Notably, five of the six participants showed at least some evidence of enhanced holistic processing. These findings indicate cognitive heterogeneity in the presentation of superior face recognition, and have implications for our theoretical understanding of the typical face-processing system and the identification of superior face-processing skills in applied settings.

Key words: Super recognisers; face recognition; individual differences; prosopagnosia.

An In-depth Cognitive Examination of Individuals

with Superior Face Recognition Skills

1. INTRODUCTION

Human faces convey an array of socially salient information, such as identity, gender, and emotional state. The ability to extract this information is critical for appropriate social functioning. While most people have similar levels of experience with faces, there are still considerable individual differences in their ability to recognise facial identity (Bate, Parris, Haslam, & Kay, 2010; Bowles et al. 2009). These differences range from individuals who are remarkably good at face recognition (so-called "super recognisers", SRs: Russell, Duchaine, & Nakayama, 2009; Bobak et al., in press) to those affected by developmental prosopagnosia (DP). This latter group of people experience severe difficulties in face recognition, in the absence of neurological damage or illness, lower-level visual or intellectual impairments, and concurrent socio-emotional difficulties (Bate & Cook, 2012; Bate et al., 2014; Jones & Tranel, 2001; Susilo & Duchaine, 2013).

While a considerable amount of research has examined the correlates of face recognition in both the typical population (e.g., Bowles et al., 2009; Wilmer, Germine, Chabris, Chatterjee, Williams, et al., 2012) and those with face recognition deficits (e.g., Barton, 2008; Behrmann, Avidan, Marotta, & Kimchi, 2005; Le Grand et al., 2006), comparatively little work has focused on the upper end of the face recognition spectrum by examining SRs. The term was first coined by Russell et al. (2009) who identified four people with extraordinary face recognition skills. This group of individuals outperformed control participants on tests of face memory, face perception, and familiar face recognition. However, it is not known whether the superior abilities of SRs extend beyond facial identity processing, nor have the underlying mechanisms of super recognition been identified. The current paper addresses these issues, presenting an in-depth cognitive assessment of six individuals who meet the criteria for super recognition. Four questions are addressed. First, we examine more general perceptual and cognitive processing mechanisms in SRs, to investigate whether enhancements in these processes support their superior face recognition skills. Second, we investigate whether SRs are only proficient at facial identity recognition, or whether their skills extend to identity *perception*. This speaks to important theoretical questions concerning the structure and function of the face-processing system. Third, we examine the processing strategies used by SRs, to investigate whether these are different or merely enhanced in comparison to typical perceivers. Finally, we pull our findings together to examine whether SRs show a consistent pattern of enhanced abilities, or whether these individuals vary in their cognitive presentation as has been observed at the bottom end of the face-processing spectrum (i.e. in DP).

1.1. General cognitive processes and super recognition

Much research supports the hypothesis that face recognition is a highly specialised process involving a number of dedicated neural circuits (Haxby, Hoffman, & Gobbini, 2000; Gobbini & Haxby, 2007), and this theoretical standpoint is supported by findings that some individuals with developmental (Duchaine & Nakayama, 2005; Jones & Tranel, 2001) and acquired (Busigny, Joubert, Felician, Ceccaldi, & Rossion, 2010; de Renzi & di Pellegrino, 1998; Ramon, Busigny, & Rossion, 2010; Ramon & Rossion, 2010; Rossion, 2014) prosopagnosia only have difficulties in the recognition of faces. Further, existing work has failed to find a relationship between face recognition skills in the typical population and performance on tests of non-facial visual memory (e.g. an abstract art memory test) or verbal memory (e.g. verbal paired-associates test) (Wilmer, Germine, Chabris, Chatterjee, Gerbasi, et al., 2012; Wilmer, Germine, Chabris, Chatterjee, Williams, et al., 2012). However, no work to date has examined the domain-specificity of super recognition, and it is possible that particularly good general perceptual or mnemonic abilities could support the exceptional face recognition skills observed in these individuals. Alternatively, if it is found that the exceptional skills of SRs are restricted only to the processing of faces, this would further support the face-specificity hypothesis.

1.2. Identity perception in super-recognition.

A fundamental practical issue in the SR literature is concerned with the classification of superior face recognition skills, and this topic has received very little attention to date. Existing research has primarily identified SRs using a cut-off of two standard deviations above the control mean on the long form of the Cambridge Face Memory Test (CFMT+; Russell et al., 2009).

Russell and colleagues (2009) also examined the perception of facial identity (i.e. by presenting images simultaneously for comparison, placing no demands on face memory) in their four SR participants, using the Cambridge Face Perception Test (CFPT; Duchaine et al., 2007). While Russell et al. make the case that their SRs also outperformed control participants on this test, it should be noted that only a group-based comparison was offered as opposed to the single-case analyses that are typically presented in cognitive neuropsychological investigations (e.g. Bate et al., 2014, 2015). However, it is near impossible for individuals to significantly outperform controls on this test using single-case comparisons given the large variation in control performance and the resulting large standard deviation. Nevertheless, it is of note that examination of the raw data (see Figure 5, Russell et al., 2009) indicates that only some SRs performed above the control mean on the CFPT. This data raises the possibility that the superior face *recognition* skills of SRs are not always associated with superior face *perception* skills.

A recent publication by Bobak and colleagues (2016) further speaks to this issue. Specifically, the SRs took part in two experiments that employed well-established paradigms representing real-world face memory and face matching tasks (e.g. the recognition of faces in high quality CCTV footage). While the SRs as a group outperformed control participants on both the matching and memory tests, some heterogeneity in performance was observed. Notably, some SRs excelled at face memory but not face matching, and vice versa; and high performance on the CFMT+ did not always correspond to superior performance on both of the applied tasks. This pattern of findings suggests there may be some cognitive and perceptual heterogeneity in individuals with superior face-processing skills. As such, an investigation of various aspects of face processing skills is of paramount importance to identify this evident heterogeneity in super recognition. It is possible that while some SRs have heightened identity-specific memory for faces, other may only enjoy facilitation at an earlier, perceptual level.

1.3. The role of holistic processing and global precedence in super recognition.

Numerous reports indicate that faces are processed in a different manner to objects (McKone & Robbins, 2011; Rossion, 2013). For example, faces are thought to be processed more holistically than other objects – that is, information is thought to be integrated from across the face rather than being broken down into individual parts (Piepers & Robbins, 2012; Rossion, 2013; see Maurer, Le Grand, & Mondloch, 2002; Richler, Palmeri, & Gauthier, 2012, for a review of different meanings of “holistic processing”). There is a long-standing belief that the use of this holistic processing style may underlie our proficiency in face recognition (e.g., Richler, Cheung, & Gauthier, 2011; Rossion, 2013), and many studies attempting to explain group or individual differences in face processing have examined indicators of holistic processing (e.g., DPs and controls: DeGutis, Cohan, Mercado, Wilmer, & Nakayama, 2012;

Palermo et al., 2011; children and adults: Crookes & McKone, 2009; Mondloch, Le Grand, & Maurer, 2002; individual differences: DeGutis Wilmer, Mercado, & Cohan, 2013; Richler et al., 2011). Given the apparent importance of holistic processing in face recognition, it is possible that super recognition is underpinned by proficiencies in this purportedly face-specific perceptual process.

Some preliminary evidence supports this hypothesis. The SRs reported by Russell et al. (2009) showed a larger face inversion effect (a difference in performance between upright and inverted faces) than control participants. The inversion effect is thought to reflect the fact that face-specific perceptual processes such as holistic processing are specialised for upright faces, and are disturbed or reduced in inverted faces (Maurer et al., 2002; Ramon et al., in press; Richler et al., 2011). Therefore, a larger inversion effect is thought to reflect stronger holistic processing, and the fact that SRs showed superior performance for upright faces but relatively normal performance for inverted faces indicates that they may show particularly strong holistic processing.

While the inversion effect is taken as an index of holistic processing, it may also reflect other face-specific processes such as discrimination of spacing (Maurer et al., 2002). As such, many researchers agree that another measure – the composite task – is the most robust indicator of holistic processing in group studies (Richler, Floyd, & Gauthier, 2014). Existing work indicates that the composite effect does correlate with face recognition abilities in the general population (Richler et al., 2011; Wang, Li, Fang, Tian, Liu, 2012, c.f. Konar, Bennett, & Sekuler, 2010), and that it is reduced in people with prosopagnosia (Avidan, Tanzer, & Behrman, 2011; Palermo et al., 2011; but see Susilo et al., 2010). To date though, no studies have addressed this question directly in SRs, and it remains unclear whether stronger than usual holistic processing underpins superior face recognition skills.

It is important to note that although holistic processing is thought to be significantly heightened for faces compared to other objects (e.g., Robbins & McKone, 2007), it also occurs on a more general scale (e.g., integrating many different objects into a coherent visual scene). This tendency of an individual to focus on this global picture (as opposed to isolated parts) is often referred to as global precedence (e.g., Duchaine, Yovel, & Nakayama, 2007). Manipulating this general process by asking individuals to focus on local details (e.g. the small letters in a Navon stimulus) can be detrimental to face recognition, possibly because it encourages piecemeal, non-holistic processing (e.g. Gao, Flevaris, Robertson, & Bentin, 2011; Macrae & Lewis, 2002). Building on this work, some research into prosopagnosia has established that some people with face recognition deficits show a general bias towards the processing of local details, and this correlates with their reduced holistic processing of faces (Avidan et al., 2011; Van Belle, Lefevre & Rossion, 2015 but see Duchaine et al., 2007). This work suggests that it may be variation in this more general global precedence, rather than face-specific holistic processing per se, that underpins individual differences face recognition abilities. Once again, though, this issue has not been addressed in the SR population.

1.4. The current investigation

The current investigation extends the existing SR literature by reporting a detailed neuropsychological assessment of six individuals who meet the criteria for super recognition. A battery of neuropsychological and cognitive tests sought to determine (a) the face-specificity of any enhancements, (b) whether superior face recognition skills also extend to identity perception, (c) whether SRs also differ from typical perceivers in holistic processing (faces) and global precedence (non-face stimuli), and (d) the consistency of these findings across the six individuals.

2. CASE DESCRIPTIONS

Following widespread media coverage about super recognition, the six individuals described in this paper contacted our laboratory. DF is an 18 year-old right-handed male Engineering student, TP is a 35 year-old right-handed male IT manager , GK is a 33 year-old right-handed male university lecturer, JN is a 35 year-old right-handed female sourcing consultant, CH is a 27 year-old right-handed male lawyer, and CW is a 21 year-old Psychology graduate. All but one of the participants (GK) has been described in previous published work examining super recognition (Bobak et al.,2016a, 2016b).

In an initial informal interview, all the SRs described extraordinary face recognition skills that have been present from an early age. They reported that they are able to recognise people even after a brief encounter or after many years have passed (for instance, childhood friends): "I recently saw a girl who I taught for a couple of swimming lessons when I was a teenager. I recognised her immediately, despite the fact that I had not seen her since she was 6, and she is now 18" (CH). Following existing procedure, each participant was screened using the CFMT+ (Russell et al., 2009, see Figure 1).

< Insert Figure 1 >

All six SRs achieved CFMT+ scores that are above the previously-used cut-off of 90/102 (Bobak, Dowsett, & Bate, 2016a; Bobak et al., 2016b; Bobak, Parris, Gregory, Bennetts, & Bate, in press; Russell et al., 2009, 2012) on this test (see Table 1). However, we also collected our own control data (N = 30, 15 female; mean age = 25.9 years, SD = 4.5) to ensure that we were comparing our SRs to an appropriately matched control group. Single case statistics showed that all the SRs but one (TP) significantly outperformed the control group: CW and GK, $t(32) = 2.66$, $p = .01$, $Z_{cc} = 2.70$, 95% CI [1.917, 3.474]; estimated % population below their scores = 99.37 and JN, CH and DF, $t(32) = 2.40$, $p = .02$, $Z_{cc} = 2.445$ (95% CI: 1.718 – 3.160); estimated % population below their scores = 98.86. Given TP reached the criteria for super recognition based on previously published control data (Russell et al., 2009) and two additional tests of face recognition (see Bobak et al., 2016b), we still included him in our sample for this investigation.

< *Insert Table 1* >

All SRs reported normal or corrected-to-normal vision. General intelligence was assessed using the Wechsler Abbreviated Scale of Intelligence, Second Edition (WASI-II, Wechsler, 2011). One SR performed within the “average” range (JN), whereas TP, DF, CH and GK were within the “superior” range (see Table 1). Due to limited time availability, CW’s intelligence was estimated using the WTAR (Holdnack, 2001). Similarly to JN, he scored within the “average” range. While CH excelled at the verbal component of the measurement, DF and JN showed a clear advantage on the performance rather than verbal sub-tests. Conversely, both TP and GK performed similarly on the two sub-tests. This variation in IQ is in line with findings that face recognition ability is domain-specific and unrelated to general intelligence (Wilmer et al., 2009; Zhu et al., 2010).

For each of the investigations below, performance of the SRs is compared to controls using at least two tests to address each theoretical question. For each individual test, a subset of individuals were extracted from a control group containing 30 gender- and age-matched participants (19 female, M age = 32.1, SD = 9.3; see Table 1). These individuals were also matched to the SRs according to estimated IQ (using the Wechsler Test of Adult Reading, WTAR; Holdnack, 2001) and had typical face recognition skills (as confirmed by their performance on the CFMT+: see Table 1). Note that a larger control sample is reported for the CFPT, due to the larger variability in the typical population on this test (see below). All control participants presented with normal visual acuity and contrast sensitivity. Not all control participants completed all tests due to time constraints and some computer errors (the N for individual tests is presented in Tables 1-4; gender was approximately equal for each test). For each test, the SRs were compared to the controls on a single case level, using modified *t*-tests for single case comparisons (SINGLIMS, Crawford, Garthwaite, & Porter, 2010) or Revised Standardised Differences Tests (RSDT, Crawford et al., 2010) as appropriate. This is a particular strength of this work as previous studies (Russell et al. 2009; Russell et al., 2012) have only used group-based statistics to analyse the performance of a smaller number of SRs. Informed consent was obtained from all participants, and ethical approval for the study was granted by the departmental ethics committee.

3. STUDY 1: IS SUPER RECOGNITION FACE-SPECIFIC?

As discussed above, previous work examining super recognition has focused exclusively on their face recognition performance, and it remains possible that the skill is supported by enhancements in more generalized cognitive, perceptual or mnemonic skills. Our first investigation sought to address this issue by examining performance on two different object-processing tests: one assessing matching skills, and the other memory skills.

3.1. Matching test

An object and face matching test was created within our laboratory to assess whether SRs show superior object processing skills compared to typical participants. Participants completed a sequential same/different matching task with faces, hands, and houses (see Figure 2). Each trial consisted of two sequentially presented objects – the initial study image was displayed for 250 ms, and the second test image was displayed until the participant responded. In the face condition, the study image showed a face from a frontal viewpoint and the test image showed a face from a 30-45° angle. Faces were drawn from the Cambridge Face Memory Test–Australian (McKone et al., 2011) and the Bosphorous Face Database (Savran et al., 2012), and were edited to remove external features. Houses were created using the software Realtime Landscaping Plus (Idea Spectrum Inc., 2012). Each house contained the same number of features (three sets of windows and a door), placed onto a constant background texture. The shape and location of the features, the luminance of the background texture, and the overall shape of the house varied throughout the set. As in the face condition, the study and test images presented the houses from two different viewpoints (frontal and 15° profile). Hand images were extracted from the Bosphorus Hand Database (Dutağacı, Yörük & Sankur, 2008), and showed the palm and fingers of a hand. Images were chosen to exclude rings, watches, cuffs, or other identifying features. Study and test images showed the hands in two different positions (e.g., fingers splayed and fingers together), with the wrist pointing downwards (upright condition) or upwards (inverted condition). Each category contained 32 pairs of images (16 same identities, 16 different identities). All pairs were presented twice upright and twice inverted. Trials were blocked by stimulus type, with upright and inverted trials presented randomly within each stimulus type. The order of blocks was randomised between participants. The measure *d'* (a bias-free measure of sensitivity; MacMillan & Creelman, 2005) was calculated for category of stimulus, and used in all analyses.

<Insert Figure 2>

An ANOVA on control participants' data revealed main effects of object, $F(2,19) = 26.99$, $p < .0005$, $\eta_p^2 = .74$, and orientation, $F(1,20) = 31.57$, $p < .0005$, $\eta_p^2 = .61$, and a significant interaction between object and orientation, $F(2,19) = 23.40$, $p < .0005$, $\eta_p^2 = .71$. Pairwise comparisons (Bonferroni corrected) confirmed that control participants showed a significant inversion effect for faces ($p < .0005$), but not for hands ($p = .325$) or houses ($p = .072$) (see Table 2).

< Insert Table 2 >

On an individual level, two SRs (JN and DF) were significantly better at matching upright faces than control participants, JN: $t(20) = 3.22$, $p = .004$, $Z_{CC} = 3.30$ (95% CI: 2.19 -

4.39), estimated % of population below JN's score = 99.78%; DF: $t(20) = 2.80$, $p = .011$, $Z_{CC} = 2.86$ (95% CI: 1.88 – 3.84), estimated % of population below DF's score = 99.44% (see Table 2). TP, CH, GK, and CW performed better than control participants, but these differences did not reach significance (*p*s > .1)[1]. Single case analyses showed no significant differences between controls and SRs when matching upright hands (*p*s > .15) or houses (*p*s > .25), nor any inverted objects (all *p*s > .07), except for GK who was significantly better than the control group at the matching of inverted hands, $t(20) = 2.22$, $p = .042$, $Z_{CC} = 2.19$, 95% CI [1.405, 3.015), estimated % of population below GK's score = 97.88 (see Table 1). However, the same participant was significantly worse than controls at matching inverted houses, $t(20) = -4.26$, $p < .001$, $Z_{CC} = -4.36$, 95% CI [-5.767, -2.951], estimated % of population below GK's score = 0.02. It is of note, though, that negative d' values can suggest that the participant did not correctly follow the instructions, and it is possible that GK misunderstood the response labelling in this part of the task.

RSDT comparing the inversion effect of individual SRs for faces revealed that JN and DF showed a significantly greater effect of inversion than controls for faces, JN: $p = .004$ $Z_{DCC} = 3.30$ (95% CI: 2.18 – 4.57), estimated % of population showing a larger difference than JN = 0.21%; DF: $p = .013$, $Z_{DCC} = 2.75$ (95% CI: 1.78 – 3.85), estimated % of population showing a larger difference than DF = 0.68%[2]. TP, GK and CW did not show a disproportionate inversion effect when compared to controls (*p*s > .07). GK, however showed a significantly greater level of inversion than controls for houses, $p < .001$, $Z_{DCC} = 6.59$ (95% CI: 4.54 – 8.96), estimated % of population showing a larger difference than GK = 0.0004%. Moreover, CH showed a larger inversion effect for hands, $p = .02$, $Z_{DCC} = 2.54$ (95% CI: 1.67 – 3.52), estimated % of population showing a larger difference than CH = 1.4.

[1] Discussion of performance on the upright faces condition is expanded below in our consideration of face perception skills (see section 4.2).
[2] Further discussion of inversion effects on this task can be found in section 5.2.

To address the potential discrepancies in the difficulty of face and object blocks of the matching task, we performed a mixed 3 x 2 ANOVA between the stimuli type (faces, hands, houses) and the orientation (upright, inverted) for all control participants. The analyses revealed main effect of stimuli type, $F(2,40) = 35.79$, $p < .001$; $\eta_p^2 = .642$; orientation, $F(1,20) = 31.57$. $p < .001$, $\eta_p^2 = .612$; and a significant interaction between these two factors, $F(2,40) = 22.99$, $p < .001$, $\eta_p^2 = .535$. Pairwise comparisons for upright stimuli revealed no difference in difficulty between faces and hands ($p = 1$), but participants matched houses significantly better than faces and hands (*p*s < .001). Whilst these analyses may suggest that the house stimuli block was easier than face and hands blocks, critically there was no evidence of inversion effect in neither hands, nor houses matching trials ($p = .325$ and $p = .072$ respectively), but a clear inversion effect for the face matching task ($p < .001$). Taken together, the face, hands, & houses matching test appears to be suitable for assessment of differences in processing of faces and various classes of biological and non-biological stimuli.

In sum, this investigation presents little evidence that SRs excel at the perception and recognition of objects in a matching task that places no demands on long-term memory. Only GK displayed enhanced processing in one object condition (inverted hands), yet also showed diminished processing of inverted houses. While it is likely that the latter finding represents a misunderstanding of task instructions, further investigation is required with this individual to present convincing evidence of enhanced object-processing capabilities.

3.2. Object memory

Memory for objects was assessed using the Cambridge Car Memory Test (CCMT; Dennett et al., 2012). The CCMT is an object equivalent of the CFMT – like its face counterpart, participants are required to learn six cars, then choose which of three presented cars is one of the learnt set. The CCMT consists of 72 trials across three blocks, which become progressively more difficult. Although single-case analyses indicated that all SRs scored within the normal range (all *p*s > .05; see Table 2), it should be noted that, for male participants, even a perfect score on this test would not be considered significantly greater than controls (*p* = .088 for 100% accuracy). However, examination of the raw scores on this test indicates that only one individual (TP) approached ceiling on this task, scoring 71/72 (all other participants achieved scores that were within 1 SD of the control mean). Further, TP reported that he does not have a particular interest in cars, raising the possibility that his superior memory skills may generalize beyond faces.

3.3. Summary of Study 1

Four of the six SRs failed to show any evidence of superior processing of objects, on either a matching or a memory task. These findings suggest that, at least in some cases, super recognition is domain-specific. While CW outperformed controls at the matching of inverted hands, it is of note that his performance was not heightened in any other condition, nor on the memory task. Further investigation is required with this individual to convincingly conclude that his object processing skills are also superior to those of typical perceivers. The case of TP is of interest, given his near-ceiling performance on the object memory task. Given he did not outperform controls on the matching task, it is possible that his superior face recognition skills are underpinned by more general enhancements in memory.

4. STUDY 2: PERCEPTION OF FACIAL IDENTITY

Our second investigation examined the perception of facial identity. This examination asks an important question, whether face memory is specific to face-related mnemonic expertise, as assessed by the CFMT+, or extends to other aspects of face processing.

4.1. CFPT

The CFPT (Duchaine et al., 2007) requires participants to arrange six faces displayed from a frontal viewpoint in order of their similarity to a target face that is presented in a three-quarter viewpoint. The six test faces were created by morphing target faces with distractor faces. Participants complete 16 trials in total: eight with the faces upright and the remainder in an inverted format. Performance on the CFPT is measured as the total number of errors (i.e., how far away the participant is from a perfect arrangement), so that a lower score reflects better performance. Because there is some variability in the scores achieved by typical participants on the CFPT (Bowles et al., 2009), control data was collected from a larger sample of controls (N = 58, see Table 3). Nevertheless, the standard deviation for our sample was still relatively large (as observed in previous work, Russell et al., 2012), preventing any single-case analyses on the upright condition from reaching significance (all *p*s > .17)[3]. It is of note, though, that all participants bar one (CH) outperformed controls by at least one standard deviation. Further, the scores that were achieved are similar to those reported by Russell et al. (2009), which were significantly better than controls in a group-based analysis.

< *Insert Table 3* >

4.2. Matching test

Given the statistical difficulties in identifying superior performance on the CFPT, we further assessed face perception skills by considering performance in the "upright face" condition of our matching task described above (see section 3.1 and Table 2). On this task, two of the SRs – JN and DF – showed an exceptional ability to match upright faces compared to controls. Pertinently, DF also achieved the most proficient score on the upright condition of the CFPT.

[3] Analysis of the inverted condition on this test is presented in our discussion of holistic processing below (see section 5.4).

4.3. Summary of Study 2.

This study examined whether SRs excel at the perception of facial identity. The results suggest that some SRs (JN and DF) are particularly adept at extracting and/or using facial identity information. The large standard deviation in the control data of the CFPT task may have obscured the emergence of differences on individual level. Pertinently, the CFPT has been developed for studies with DP participants and may not be calibrated for detection of differences between the typical and superior performance as well as it is for the assessment of perceptual impairment in face blind participants.

5. STUDY 3: THE ROLE OF HOLISTIC PROCESSING AND GLOBAL PRECEDENCE IN SUPER RECOGNITION.

Our final investigation presents a series of experiments that examine each SR's tendency to process generic stimuli at a global level (global precedence; the Navon task) and more face-specific holistic processing skills (inversion effects and the composite task). Given both of these processing styles have been associated with face recognition skills in typical perceivers (e.g., Macrae & Lewis, 2002; Richler et al., 2011) and people with prosopagnosia (e.g., Avidan et al., 2011; Duchaine et al., 2007), it may be that SRs show a particularly strong tendency to process stimuli in a global or holistic fashion.

5.1. The Navon task

Global precedence was examined using a global-local task that requires participants to identify letters at various scales (Navon, 1977). In this test, participants are presented with composite stimuli of small letters making up big letters (e.g., many small "S" letters arranged in the shape of the letter "H"), and asked to identify either the large or small letter. In this version of the test, the stimuli were presented in four different positions, so participants could not focus on any particular part of the screen. The test was divided into four blocks of 48 trials each. In two blocks, volunteers had to respond to the large letter and in the other two blocks, they responded to the small letter. On half of the trials the composite letters were congruent (small and large letters were the same) and on the other half they were incongruent (small and large letters were different).

In order to examine whether the extraordinary performance of SRs in facial identity tasks results from a stronger global bias, an index of global bias was calculated (Duchaine, Germine, & Nakayama, 2007) by dividing average global RT by average local RT ([Global congruent RT + Global incongruent RT] / 2)/([Local congruent RT + Local incongruent RT] / 2). Index values below one indicate a global bias; index values above one indicate a local bias. Comparisons for individual SRs revealed that JN's global bias index was significantly lower than the control group, JN: $t(27) = -2.95$, $p = .003$, $Z_{CC} = -3.00$ (95% CI: -3.87 - -2.12), estimated % of population below JN's score = 0.33%, suggesting a particularly strong bias to process stimuli globally (see Table 4). None of the other SRs showed a similar effect (all *p*s > .1).

< Insert Table 4 >

5.2. Inversion effects

Much previous work has examined holistic processing by comparing performance on an upright face recognition task with performance on an inverted condition. The two face perception tasks described above (see Section 4.1) contain both upright and inverted conditions, and we revisit the findings of these tasks to evaluate the use of holistic processing in super recognition.

CFPT: To examine whether SRs showed a disproportionate inversion effect, we subtracted each participant's score for inverted trials from their score for upright trials, then divided it by their score for upright trials to create an inversion index ([upright-inverted]/[upright]; Russell et al., 2009). The mean inversion effect for the SR group in this study was 2.14 (*SD* = 0.6), in line with Russell et al. (2009), who reported the inversion effect of SRs to be 2.3 (*SD* = 0.2). Single case analyses on the inversion index revealed an enhanced effect of inversion for two SRs, CW, $t(57) = 2.15$, $p = .038$, $Z_{cc} = 2.171$, 95% CI [1.691 – 2.636], % of population below CW's score: 98.09; and DF, $t(61) = 2.59$, $p = .01$, $Z_{cc} = 2.611$, 95% CI [2.069 – 3.156], % of population below DF's score: 99.35 (see Table 4). Although the inversion indices of the remaining SRs did not significantly differ from the control group (all *p*s > .12), it should be noted that CH, JN and GK all achieved scores that were approximately two SDs above the control mean. This finding may be interpreted as evidence that all SRs other than TP show evidence of heightened holistic processing (i.e. that was approximately or above 2 SDs from the control mean) for upright faces.

Matching test: Analysis of performance on the upright versus inverted "face" conditions of this task provides a further assessment of holistic processing with respect to inversion effects. RSDT comparing the inversion effect of individual SRs for faces revealed that JN and DF showed a significantly greater effect of inversion than controls for faces, JN: $p = .004$ $Z_{DCC} = 3.30$ (95% CI: 2.18 – 4.57), estimated % of population showing a larger difference than JN = 0.21%; DF: $p = .013$, $Z_{DCC} = 2.75$ (95% CI: 1.78 – 3.85), estimated % of population showing a larger difference than DF = 0.68%. Three (CH, CW, and TP) of the remaining four SRs performed more than 1.5 SDs above the control mean, with only GK performing in a similar manner to controls (see Tables 2 and 4).

Hence, enhanced inversion effects are most consistently seen across the CFPT and matching task in three of the SRs (CW, DF and JN), with trends also noted consistently in

CH. TP and GK only showed a trend towards a heightened inversion effect in one of the two tasks.

5.3. The composite task

While inversion effects have traditionally been used to evaluate holistic processing skills, it is generally accepted that they only offer reasonable indicators of the measure and are not directly diagnostic of processing style (e.g., Valentine, 1988). For example, a disproportionate effect of inversion may arise due to difficulties processing local feature information, rather than a more integrative processing style per se (McKone & Yovel, 2009). The composite task is seen as a more direct measure of holistic processing (Rossion, 2013), although performance on this task is variable even in typical perceivers, making it difficult to interpret null results in single case analyses (Konar et al., 2010; Richler et al., 2011). Nevertheless, we administered this task to our SR group.

In the composite task, participants are presented with faces that have been cut in half. The top half of one face is combined with the bottom half of another face, either aligned (i.e., creating the impression of a full face) or misaligned (the two halves are offset). Previous studies have found slower or less accurate performance in face matching tasks when the face halves are aligned than when they are misaligned (e.g., Le Grand, Mondloch, Maurer, & Brent, 2004; Robbins & McKone, 2007, Young et al., 1987). This effect is thought to reflect holistic processing – when the faces are aligned, participants automatically integrate information from the irrelevant bottom halves of the composite faces, which creates the percept of two different faces. When the faces are not aligned, no holistic processing occurs, and participants are able to match the top halves without interference from the irrelevant bottom half (Rossion, 2013). Since holistic processing is thought to be disrupted when faces are presented upside-down (Maurer, et al., 2002), and to be reduced or not be present for objects other than faces (McKone & Robbins, 2011), the same effect does not occur for inverted composite faces or objects other than faces. Thus, if SRs show holistic processing of faces, we would expect greater interference (i.e., worse performance) than controls for upright aligned faces when compared with upright misaligned faces. If this effect is related to face-specific processing, the same pattern of results would not be present for inverted faces or objects.

In this study, we adapted the composite paradigm used by Robbins and McKone (2007) to examine holistic processing for faces and dogs[4]. Participants were presented with two composite faces or dogs sequentially. The first stimulus appeared for 600 ms, the second stayed onscreen until the participant responded. The stimuli were offset by 25% of the screen size, to prevent matching based on the size or location of the stimuli or features. Participants were asked to indicate as quickly and as accurately as possible whether the top halves of the face or dog (the section with the eyes) were the same or different. The stimuli were identical to those used by Robbins and McKone (2007), except that only 30 stimuli (15 same identity, 15 different identity) were presented in each condition (upright and inverted; aligned and misaligned; faces and dogs). Trials were blocked by object and orientation, with aligned and misaligned trials presented randomly within each condition. Analyses were conducted on accuracy and reaction time (RT). Further, as some participants show a composite effect for accuracy, but not reaction time, and other participants show the opposite effect, we used the combined measure inverse efficiency (IE) ([reaction time]/[accuracy], Townsend & Ashby, 1978;1983) to assess the extent of the composite effect (Rossion, 2013). In line with Bruyer

[4] There has been much debate in the literature over the use of this traditional composite task (sometimes referred to as the “partial design”) in comparison to a longer version (sometimes referred to as the “complete design”) (see Gauthier & Bukach, 2007; McKone & Robbins, 2007; Richler & Gauthier, 2013, 2014; Rossion, 2013 for an overview). We elected to use the current version for several reasons: primarily, the fact that the complete design has been shown to elicit a strong composite effect for inverted faces and objects (e.g., Richler, Mack, Palmeri, & Gauthier, 2011), whereas the stimuli used by Robbins and McKone (2007) show no evidence of a composite effect for either stimulus. Other theoretical justifications for the use of the traditional composite task (e.g., the perceptual and neural locus of the effect) have been comprehensively reviewed by Rossion (2013).

and Brysbaert (2011), we report results from all three analyses, but Table 4 shows results for IE only (as these were broadly in line with accuracy). Follow-up analyses were conducted on the composite effect ([IE aligned] – [IE misaligned]) for each stimulus and orientation.

Control participants showed a typical pattern of results for both accuracy and IE: there was a significant interaction between stimulus (face and dog), orientation (upright and inverted), and alignment (aligned and misaligned), accuracy: $F(1,28) = 12.34$, $p = .002$, $\eta_p^2 = .31$; IE: $F(1,28) = 11.48$, $p = .002$, $\eta_p^2 = .29$. Follow-up analyses on the composite effect found a significantly greater effect of alignment for upright faces than for inverted faces (accuracy: $p = .001$; IE: $p = .001$) or upright dogs (accuracy: $p < .0005$ IE: $p < .0005$), suggesting stronger holistic processing for upright faces than inverted faces or non-face stimuli (see Table 4). While the pattern of results for RT appeared to show a numerical composite effect, this effect was not significant: there was no significant three-way interaction in the RT analyses, $F(1,28) = 1.50$, $p = .230$, $\eta_p^2 = .05$; as such, follow-up analyses were not conducted on the composite effect for RT.

Single case analyses on accuracy revealed no significant differences in the size of the composite effect between any of the SRs and control participants (all *p*'s > .1). The analysis of RT showed that one SR (JN) showed a significantly stronger composite effect for upright faces than controls, $t(29) = -3016$, $p = .02$, $Z_{CC} = -2.19$ (95% CI: -2.87 - -1.51), estimated % of population below TP's score = 98.03%. Analyses of IE showed that one SR (TP) showed a significantly stronger composite effect for upright faces than controls, $t(29) = 2.16$, $p = .04$, $Z_{CC} = 2.193$ (95% CI: 1.51- 2.86), estimated % of population below TP's score = 98.01%. None of the other SRs showed an enhanced composite effect (all *p*'s > .6).

To examine whether JN's and TP's composite effects were disproportionate for upright faces (i.e., whether this reflects face-specific mechanisms or a more general proficiency at holistic processing), we carried out RSDT comparing the composite effect for upright faces to that for inverted faces and upright dogs. For both JN and TP, the difference in composite effects for upright and inverted faces was within the normal range compared to control participants (JN: p = .22; TP: p = .14). Similarly, the difference between JN's composite effect for faces and dogs was not disproportionate compared to controls (p = .19). However, TP showed a significantly stronger composite effect for faces than for dogs when compared to control participants, p = .001, Z_{CC} = 3.59 (95% CI: 2.63- 4.64), estimated % of population showing a larger difference than TP = 0.06%. This indicates that TP was not showing an increased composite effect for all stimuli – rather, he showed evidence of enhanced holistic processing specifically for faces.

5.4. Summary of Study 3

Study 3 initially examined whether SRs display an enhanced general global processing bias via performance on the Navon task, and this was only observed in one participant (JN). Evidence of enhanced face-specific holistic processing was investigated using face inversion effects, where they were consistently observed in three SRs (CW, DF and JN), and trends were noted across both tasks in CH. However, TP and GK only showed a trend towards a heightened inversion effect in one of the two tasks. Finally, we examined holistic processing using the composite task, where it is more difficult to observe significant differences in single-case comparisons. However, TP demonstrated enhanced holistic processing of faces on this test; JN also showed enhanced holistic processing in the composite task, but our analyses did not indicate that this enhancement was disproportionate for upright faces. Given that JN did not show an enhanced composite effect in the inverse efficiency analysis, it is possible that our results reflect a speed-accuracy trade-off. In sum, while a more generalised global bias was observed in one participant, evidence of enhanced face-specific holistic processing was observed in all participants but GK.

6. GENERAL DISCUSSION

In this paper, we report a detailed cognitive assessment of the face- and object-processing skills of six individuals who meet the published diagnostic criteria for super recognition. We specifically addressed four key theoretical issues: (a) the domain-specificity of super recognition, (b) whether super recognition extends to the perception of facial identity, and (c) whether super recognition is underpinned by enhanced holistic processing or global precedence. Each of these issues is discussed in turn below.

6.1. Domain-specificity of super recognition

Two tests assessed the ability of SRs to process non-facial stimuli: one required the matching of faces compared to houses and hands, and the other test assessed memory for cars (the CCMT) in a paradigm that replicates the standard version of the CFMT. Enhanced performance was only observed in the object conditions of the matching task in one SR participant (GK). However, enhanced performance was only observed in the inverted hands condition in this participant, and not the remaining three object conditions, nor the inverted faces condition. This finding therefore only presents limited evidence regarding the object matching skills of this individual, and it is of note that he did not outperform controls on the CCMT. However, the latter was observed in one other participant (TP). Given the matching task measures different processes to the CCMT, it is possible that TP's enhanced performance on this test results from generalised superior memory skills which would not have aided his performance on the matching task.

Most significantly though, four of the six SRs displayed domain-specificity for faces in the first investigation. Given later investigations indicated one of these participants (JN) also displayed an enhanced general global processing bias, a more conservative conclusion is that domain-specificity for faces was observed in three of the six participants, providing further support for the hypothesis that face recognition is a specialised process.

6.2. Identity perception.

Our second study attempted to examine perception of facial identity. Given that prosopagnosia can broadly be partitioned into two subtypes, one involving deficits in face perception and the other higher-order impairments affecting mnemonic processes (de Renzi et al., 1997), it is possible that a similar pattern may underpin super recognition. That is, the skill may result from an enhancement in face perception.

The pattern of findings reported here suggests that only two of the six SRs (DF and JN) present with a facilitation in facial identity perception, with a further trend noted in TP. As stated above, both JN and TP may benefit from more generalised enhancements that result in their superior face recognition skills, but DF presents with domain-specific superior face recognition skills. The remaining three SRs only displayed a facilitation at the level of face memory, suggesting that super recognition may be underpinned by enhancements that are specific to memory for faces only. The data reported here therefore suggest that (a) only some SRs present with an enhancement in facial identity perception, and (b) that this may aid the construction and utilisation of view independent representations that are useful in facial identity recognition. Future studies may wish to investigate whether enhancements in facial identity perception generalise to other aspects of face perception, such as the recognition of emotional expression, age, and gender discrimination.

6.3. The role of holistic processing and global precedence in super recognition.

Our third investigation examined whether super recognition is underpinned by specific processing strategies, such as a generalised bias to process visual stimuli globally, or enhancements in face-specific holistic processing. Only one SR (JN) displayed a greater generalised bias towards global processing, which is likely to assist with face recognition (Macrae & Lewis, 2002) and may provide an explanation for her skills that is not domain-specific.

Our investigation into the use of face-specific holistic processing strategies focused around face inversion effects in two perceptual tasks, and performance on a composite test that used faces and dogs as stimuli. Enhanced inversion effects were observed in at least one of the two perceptual tasks in three SRs (DF, JN and CW), with trends also observed on at least one test in the other three participants. Inversion effects are generally interpreted as reflecting a disruption of face-specific processing (Maurer et al., 2002). It is possible that SRs in general show particularly strong integration of information across upright faces, and that these skills contribute to their exceptional ability to identify faces. However, it is also possible that SRs are particularly good at extracting facial feature information (which is also affected by inversion; McKone & Yovel, 2009). As we did not manipulate spacing or featural information in any of the tasks, our results cannot speak to SRs' ability to process isolated features or their spatial relationships.

It is important to note that an enhanced inversion effect for faces alone does not confirm that SRs show heightened face-specific processing skills. The inversion effect was also examined for two other classes of objects – houses and hands – and four of the six SRs showed typical effects of inversion compared to controls (DF, JN, CW, TP). In other words, for these four cases, the mechanisms underpinning the heightened inversion effect did not generalise to other objects.

Interestingly, while CH's inversion effects for faces in the CFPT and the matching task were on average (albeit non-significantly) greater than those of controls, he displayed an enhanced inversion effect for hands. It is thus possible that his extraordinary face recognition ability is underpinned by more general and object-relevant processing strategies, or a particular proficiency for the discrimination of biological stimuli. This specific finding is of particular relevance to the literature supporting the domain-general organisation of the human brain and the expertise account of face processing (Curby & Gauthier, 2014; McGugin, Van Gulick, & Gauthier, 2015).

The final case, GK, showed a disproportionate inversion effect for houses, although this reflects extremely poor performance (and perhaps misunderstanding of the task) in the inverted houses condition, rather than heightened performance in the upright condition. As such, it is still reasonable to conclude that the somewhat larger inversion effect for faces in the SRs reflects some level of enhanced face-specific holistic processing in at least five out of the six cases.

Only one SR (TP) demonstrated enhanced face-specific holistic processing on the composite test. A second SR (JN) showed an enhanced composite effect for faces, but unlike TP, the difference between the composite effect for faces and dogs was not disproportionate (i.e., we cannot conclude that the enhancement was face-specific). While this finding adds support to the hypothesis that this holistic processing in some form may underpin superior face processing skills in this individual, the null effects observed for the other SRs are more difficult to interpret. On one hand, large-scale studies that have examined individual differences in the composite task and face recognition abilities have not always found a significant link between the two measures (e.g., Konar et al., 2010), and fairly low correlations have been reported in studies that have detected an association ($r = .13$, Wang et al., 2012; $r = .40$-$.48$, Richler et al., 2011). This indicates that holistic processing may only play a small role in determining individual differences in face-processing, which would be entirely in line with the null effects for the majority of SRs in the current study. On the other hand, several researchers have noted that it is difficult to draw conclusions about individual differences from composite effects due to fairly low reliability of the measure (e.g., Richler & Gauthier, 2014; Rossion, 2013). Put simply, a large number of factors could have introduced noise into the composite measure (for both control participants and SRs), which may have obscured potentially significant differences between the groups. This suggests that it may be the measure of holistic processing, rather than the underlying theoretical construct, which led to null results for the majority of the SRs in this study. The fact that the majority of SRs showed a heightened effect of inversion for faces (i.e., some evidence of enhanced face-specific holistic processing) points to the latter explanation.

In sum, the evidence reported here suggests that at least five out of the six SRs display heightened face-specific holistic processing skills – even those who benefit from other facilitations in domain-general processes.

6.4. The cognitive heterogeneity of super recognition

A final point of interest regards whether the same processes might underpin the superior face recognition abilities in all six participants, or whether the presentation of super-recognition is heterogeneous. It is of note that single-case analyses revealed a disparate pattern of findings between the six SRs that may account for the superior face recognition skills in some cases. Specifically, enhancements in object processing were tentatively noted in GK and TP and JN showed a generalised bias towards global processing (see Table 5). These findings raise the possibility that enhancements in various generalised processes may contribute towards super recognition in some cases.

Further, some disparity was noted in the face-processing profiles observed across the six SRs, and even in the three whose super recognition appears to be underpinned by enhancements in face-specific mechanisms. Specifically, DF presented with enhancements in both the perception and recognition of facial identity, whereas the superior skills of CH and

CW were limited to only identity recognition. While this pattern of findings is accommodated by the predictions of dominant cognitive models of face-processing (e.g. Bruce & Young, 1986), it remains to be seen whether some individuals may present with enhanced face perception skills that do not extend to face memory performance. It is possible that such presentations may arise via repeated rehearsal in some applied settings. For instance, there is growing interest in super recognition in policing and national security settings, with reports of officers who are able to proficiently match faces across a variety of low-quality stimuli. Studies that investigate such self-reported cases and that screen the general population to assess the prevalence of super recognition may therefore bring novel case studies to light that aid the refinement of current theories of face-processing.

The findings reported here also have practical implications for the identification of SRs in both research and real-world settings. Five papers examining super recognition have been reported to date, and the first two (Russell et al., 2009, 2012) imply that facilitated performance on the CFPT (i.e. enhanced perceptual skills) are required for the "diagnosis" of super recognition. Yet, our findings demonstrate that not all SRs present with a concurrent facilitation in face perception (also see Bobak et al. 2016a; Bobak et al., 2016b). In opposition to Russell and colleagues, we used single-case statistics to compare each individual SR to control participants, and this is clearly important given the heterogeneity that has emerged in this study. Further, our work makes it clear that the CFPT is not a sufficient test with which to identify superior face perception skills, given previously published norms (e.g. Russell et al., 2012) and those reported here prevent single-case comparisons from reaching significance. This is an important issue as some applied face-processing tasks rely more on face perception than face memory, and our findings indicate that only some SRs may excel at these tasks (e.g. matching faces to identification documents at passport control, or matching the face of a suspect across different surveillance images without placing demands on memory). It is therefore necessary to develop a standardised test of face perception that does not suffer from ceiling effects.

One point of interest is that at least five of the six SRs presented with heightened holistic processing, although in two individuals this was reflected by non-significant trends that were at least 1.9 standard deviations above the control mean. This is the most consistent finding across the battery of tests that were administered to the SRs, suggesting that these individuals differ from typical perceivers in the strength or efficiency of their face-specific processing skills. Hence, heightened holistic processing may represent a common underpinning mechanism across even heterogeneous cases of super recognition, and therefore may be used as an additional diagnostic indicator to detect super recognition.

It is worth noting that the heterogenous presentation of the SRs reported here is akin to the cognitive presentation of people with DP, who fall at the opposite end of the face recognition spectrum and also present with heterogeneous cognitive profiles (Lee, Duchaine, Wilson, & Nakayama, 2010; Minnebush, Suchan, Ramon, & Daum, 2007; Schmalzl, Palermo, & Coltheart, 2008). It is of theoretical and practical value for future work to directly compare the performance of SRs to those with DP. Indeed, it may be that the latter set of individuals simply represent the poorer end of the face recognition spectrum, rather than a qualitatively different group of perceivers (but see Bobak et al., in press). Further, understanding the precise processing strategies that underpin superior face recognition will help with the development of rehabilitation training strategies that may assist those with prosopagnosia. Pertinently, if deficits present in DP have their inverse in super recognition, it is possible that rehabilitation strategies should be targeted at the level of these individual processes. Current attempts to recover face processing skills in individuals with developmental and acquired prosopagnosia have used general face matching strategies have yielded mixed results (Bate et al., 2014; Brundson, Coltheart, Nichols, & Joy, 2006; Ellis &

Young, 1988). Future attempts to rehabilitate prosopagnosia should thus perhaps concentrate on specific impairments and devise training programmes aimed at enhancing individual processes responsible for these deficits. For instance, there is some evidence to suggest that performing the “local” condition of the Navon task can have a detrimental effect on subsequent performance on a face recognition task (e.g. Macrae & Lewis, 2002) and that bias towards better processing of stimuli on a local level, i.e. in a piecemeal manner correlates inversely with face recognition abilities (Avidan et al., 2011). Conversely, JN, one of SRs in this investigation showed a very strong bias towards global stimuli and it is possible that this skill is underpinning her extraordinary face processing ability. As such, in a case of prosopagnosia where an individual shows concomitant bias towards local processing of stimuli, an intervention concentrated on overcoming this bias may be a most beneficial approach that will further generalise to improved recognition of familiar and unfamiliar faces. It is important to note that in view of failures to improve face recognition in acquired prosopagnosia (AP), such interventions may only be suitable for participants with DP where the neural circuits associated with face processing are intact. For instance, where patients affected by AP have a restricted field of view (Van Belle et al., 2015), it would be impossible to overcome bias towards local processing.

6.5. Conclusion

In sum, this investigation presents evidence that super face recognition is heterogeneous in its presentation, and in some cases may be underpinned by enhancements in more generalised processes. However, half of our SR sample displayed proficiencies that were face-specific, but nevertheless varied in whether facial identity perception was also enhanced. A facilitation in holistic processing was more consistently noted across the SR group, suggesting SRs have more developed face-specific processing strategies than typical perceivers. Such measures may present an additional indicator of superior face recognition skills. Future work should attempt to refine the method of identifying SRs, and deepen the understanding of fine-grained object and face discrimination strategies used by this population (Busigny, Graf, Mayer, & Rossion, 2010; Ramon & Van Belle, 2016). Understanding the mechanisms of superior face recognition would benefit users in applied settings where excellent face recognition ability is pivotal to national security, and aid optimal personnel allocation to tasks that are most suited to their pattern of presentation.

References

Avidan, G., Tanzer, M., & Behrmann, M. (2011). Impaired holistic processing in congenital prosopagnosia. *Neuropsychologia*, *49*(9), 2541-2552.

Barton, J. J. (2008). Structure and function in acquired prosopagnosia: lessons from a series of 10 patients with brain damage. *Journal of Neuropsychology*, *2*(1), 197-225.

Bate, S., Bennetts, R., Mole, J. A., Ainge, J. A., Gregory, N. J., Bobak, A. K., & Bussunt, A. (2014). Rehabilitation of face-processing skills in an adolescent with prosopagnosia: Evaluation of an online perceptual training programme. *Neuropsychological rehabilitation*, 1-30.

Bate, S., & Cook, S. J. (2012). Covert recognition relies on affective valence in developmental prosopagnosia: Evidence from the skin conductance response. *Neuropsychology*, *26*(5), 670.

Bate, S., Cook, S. J., Duchaine, B., Tree, J. J., Burns, E. J., & Hodgson, T. L. (2014). Intranasal inhalation of oxytocin improves face processing in developmental prosopagnosia. *Cortex*, *50*, 55-63.

Bate, S., Haslam, C., & Hodgson, T. L. (2009). Angry faces are special too: Evidence from the visual scanpath. *Neuropsychology*, *23*(5), 658.

Bate, S., Parris, B., Haslam, C., & Kay, J. (2010). Socio-emotional functioning and face recognition ability in the normal population. *Personality and Individual Differences*, *48*(2), 239-242.

Behrmann, M., Avidan, G., Marotta, J. J., & Kimchi, R. (2005). Detailed exploration of face-related processing in congenital prosopagnosia: 1. Behavioral findings. *Journal of Cognitive Neuroscience*, *17*(7), 1130-1149.

Bobak, A. K., Dowsett, A. J., & Bate, S. (2016a). Solving the Border Control Problem: Evidence of Enhanced Face Matching in Individuals with Extraordinary Face Recognition Skills. *PloS one*, *11*(2), e0148148.

Bobak, A.K., Hancock, P.J.B., & Bate, S. (2016b). Super-recognisers in Action: Evidence from Face Memory and Face Matching Tasks. *Applied Cognitive Psychology*, *30*(1), 81-91.

Bobak, A.K., Parris, B.A., Gregory, N.J., Bennetts, R.J., & Bate, S. (In press). Eye-movement strategies in developmental prosopagnosia and “super” face recognition. *Quarterly Journal of Experimental Psychology*.

Bowles, D. C., McKone, E., Dawel, A., Duchaine, B., Palermo, R., Schmalzl, L., ... & Yovel, G. (2009). Diagnosing prosopagnosia: Effects of ageing, sex, and participant–stimulus ethnic match on the Cambridge Face Memory Test and Cambridge Face Perception Test. *Cognitive Neuropsychology*, *26*(5), 423-455.

Bruce, V., & Young, A. (1986). Understanding face recognition. *British Journal of Psychology*, *77*(3), 305-327.

Brunsdon, R., Coltheart, M., Nickels, L., & Joy, P. (2006). Developmental prosopagnosia: A case analysis and treatment study. *Cognitive Neuropsychology*, *23*(6), 822-840.

Bruyer, R., & Brysbaert, M. (2011). Combining speed and accuracy in cognitive psychology: Is the inverse efficiency score (IES) a better dependent variable than the mean reaction time (RT) and the percentage of errors (PE)?. *Psychologica Belgica*, *51*(1), 5-13.

Busigny, T., Joubert, S., Felician, O., Ceccaldi, M., & Rossion, B. (2010). Holistic perception of the individual face is specific and necessary: evidence from an extensive case study of acquired prosopagnosia. *Neuropsychologia*, *48*(14), 4057-4092.

Crawford, J. R., & Howell, D. C. (1998). Comparing an individual's test score against norms derived from small samples. *The Clinical Neuropsychologist*, *12*(4), 482-486.

Crawford, J. R., Garthwaite, P. H., & Porter, S. (2010). Point and interval estimates of effect sizes for the case-controls design in neuropsychology: Rationale, methods, implementations, and proposed reporting standards. *Cognitive Neuropsychology*, *27*(3), 245-260.

Crookes, K., & McKone, E. (2009). Early maturity of face recognition: No childhood development of holistic processing, novel face encoding, or face-space. Cognition, 111, 219-247.

Curby, K. M., & Gauthier, I. (2014). Interference between face and non-face domains of perceptual expertise: a replication and extension. *Frontiers in psychology*, *5*.955.

Dalrymple, K. A., Garrido, L., & Duchaine, B. (2014). Dissociation between face perception and face memory in adults, but not children, with developmental prosopagnosia. *Developmental Cognitive Neuroscience*, *10*, 10-20.

Dennett, H. W., McKone, E., Tavashmi, R., Hall, A., Pidcock, M., Edwards, M., & Duchaine, B. (2012). The Cambridge Car Memory Test: A task matched in format to the Cambridge Face Memory Test, with norms, reliability, sex differences, dissociations from face memory, and expertise effects. *Behavior Research Methods*, *44*(2), 587-605.

De Renzi, E., & Di Pellegrino, G. (1998). Prosopagnosia and alexia without object agnosia. *Cortex*, *34*(3), 403-415.

DeGutis, J., Cohan, S., Mercado, R. J., Wilmer, J., & Nakayama, K. (2012). Holistic processing of the mouth but not the eyes in developmental prosopagnosia. *Cognitive Neuropsychology*, *29*(5-6), 419-446.

DeGutis, J., Wilmer, J., Mercado, R. J., & Cohan, S. (2013). Using regression to measure holistic face processing reveals a strong link with face recognition ability. *Cognition*, *126*(1), 87-100.

Duchaine, B., Germine, L., & Nakayama, K. (2007). Family resemblance: Ten family members with prosopagnosia and within-class object agnosia. *Cognitive Neuropsychology*, *24*(4), 419-430.

Duchaine, B., & Nakayama, K. (2005). Dissociations of face and object recognition in developmental prosopagnosia. *Journal of Cognitive Neuroscience*, *17*(2), 249-261.

Duchaine, B., & Nakayama, K. (2006). The Cambridge Face Memory Test: Results for neurologically intact individuals and an investigation of its validity using inverted face stimuli and prosopagnosic participants. *Neuropsychologia*,*44*(4), 576-585.

Duchaine, B. C., Parker, H., & Nakayama, K. (2003). Normal recognition of emotion in a prosopagnosic. *Perception*, *32*(7), 827-838.

Duchaine, B. C., Yovel, G., Butterworth, E. J., & Nakayama, K. (2006). Prosopagnosia as an impairment to face-specific mechanisms: Elimination of the alternative hypotheses in a developmental case. *Cognitive Neuropsychology*, *23*(5), 714-747.

Duchaine, B., Yovel, G., & Nakayama, K. (2007). No global processing deficit in the Navon task in 14 developmental prosopagnosics. *Social Cognitive and Affective Neuroscience*, *2*(2), 104-113.

Dutağacı, H., Yörük, E., & Sankur, B. (2008). Comparative analysis of global hand appearance-based person recognition. *Journal of Electronic Imaging*, *17*(1), 011018-011018.

Eimer, M. (2000). Event-related brain potentials distinguish processing stages involved in face perception and recognition. *Clinical Neurophysiology*, *111*(4), 694-705.

Eimer, M., Gosling, A., & Duchaine, B. (2012). Electrophysiological markers of covert face recognition in developmental prosopagnosia. *Brain*, *135*(2), 542-554.

Eimer, M., & McCarthy, R. A. (1999). Prosopagnosia and structural encoding of faces: Evidence from event‐ related potentials. *Neuroreport*, *10*(2), 255-259.

Ellis, H. D., & Young, A. W. (1988). Training in face‐ processing skills for a child with acquired prosopagnosia. *Developmental Neuropsychology*, *4*(4), 283-294.

Gao, Z., Flevaris, A. V., Robertson, L. C., & Bentin, S. (2011). Priming global and local processing of composite faces: revisiting the processing-bias effect on face perception. *Attention, Perception, & Psychophysics*, *73*(5), 1477-1486.

Garrido, L., Duchaine, B., & Nakayama, K. (2008). Face detection in normal and prosopagnosic individuals. *Journal of Neuropsychology*, *2*(1), 119-140.

Gauthier, I., & Bukach, C. (2007). Should we reject the expertise hypothesis? *Cognition, 103*(2), 322-330.

Gobbini, M. I., & Haxby, J. V. (2007). Neural systems for recognition of familiar faces. *Neuropsychologia*, *45*(1), 32-41.

Haxby, J. V., Hoffman, E. A., & Gobbini, M. I. (2000). The distributed human neural system for face perception. *Trends in Cognitive Sciences*, *4*(6), 223-233.

Holdnack, H. A. (2001). *Wechsler Test of Adult Reading: WTAR*. Psychological Corporation: San Antonio, TX.

Jones, R. D., & Tranel, D. (2001). Severe developmental prosopagnosia in a child with superior intellect. *Journal of Clinical and Experimental Neuropsychology*, *23*(3), 265-273.

Konar, Y., Bennett, P. J., & Sekuler, A. B. (2010). Holistic processing is not correlated with face-identification accuracy. *Psychological Science*, *21*(1), 38-43.

Lee, Y., Duchaine, B., Wilson, H. R., & Nakayama, K. (2010). Three cases of developmental prosopagnosia from one family: Detailed neuropsychological and psychophysical investigation of face processing. *Cortex*, *46*(8), 949-964.

Le Grand, R., Cooper, P. A., Mondloch, C. J., Lewis, T. L., Sagiv, N., de Gelder, B., & Maurer, D. (2006). What aspects of face processing are impaired in developmental prosopagnosia? *Brain and Cognition*, *61*(2), 139-158.

Le Grand, R., Mondloch, C. J., Maurer, D., & Brent, H. P. (2004). Impairment in holistic face processing following early visual deprivation. *Psychological Science*, *15*(11), 762-768.

Macmillan, N. A., & Creelman, C. D. (2005). Detection theory: A user's guide. Psychology press.

McGugin, R. W., Van Gulick, A. E., & Gauthier, I. (in press). Cortical Thickness in Fusiform Face Area Predicts Face and Object Recognition Performance.*Journal of Cognitive Neuroscience*.

Macrae, C. N., & Lewis, H. L. (2002). Do I know you? Processing orientation and face recognition. *Psychological Science*, *13*(2), 194-196.

Maurer, D., Le Grand, R. L., & Mondloch, C. J. (2002). The many faces of configural processing. *Trends in Cognitive Sciences*, *6*(6), 255-260.

McKone, E., Hall, A., Pidcock, M., Palermo, R., Wilkinson, R. B., Rivolta, D., ... & O'Connor, K. B. (2011). Face ethnicity and measurement reliability affect face recognition performance in developmental prosopagnosia: Evidence from the Cambridge Face Memory Test–Australian. *Cognitive Neuropsychology*, *28*(2), 109-146.

McKone, E., & Robbins, R. (2007). The evidence rejects the expertise hypothesis: Reply to Gauthier & Bukach. *Cognition*, *103*(2), 331-336.

McKone, E., & Robbins, R. (2011). Are faces special. In A. J. Calder, G. Rhodes, M. H. Johnson, & J. V. Haxby (Eds.), The Oxford handbook of face perception (pp. 149-176). Oxford, UK: Oxford University Press.

McKone, E., & Yovel, G. (2009). Why does picture-plane inversion sometimes dissociate perception of features and spacing in faces, and sometimes not? Toward a new theory of holistic processing. *Psychonomic Bulletin & Review*,*16*(5), 778-797.

Minnebusch, D. A., Suchan, B., Ramon, M., & Daum, I. (2007). Event-related potentials reflect heterogeneity of developmental prosopagnosia.*European Journal of Neuroscience*, *25*(7), 2234-2247.

Mondloch, C. J., Le Grand, R., & Maurer, D. (2002). Configural face processing develops more slowly than featural face processing. *Perception*, *31*(5), 553-566.

Navon, D. (1977). Forest before trees: The precedence of global features in visual perception. *Cognitive Psychology*, *9*(3), 353-383.

Palermo, R., Willis, M. L., Rivolta, D., McKone, E., Wilson, C. E., & Calder, A. J. (2011). Impaired holistic coding of facial expression and facial identity in congenital prosopagnosia. *Neuropsychologia*, *49*(5), 1226-1235.

Piepers, D. W., & Robbins, R. A. (2012). A review and clarification of the terms "holistic,""configural," and "relational" in the face perception literature. *Frontiers in Psychology*, *3*, 559.

Ramon, M., Busigny, T., & Rossion, B. (2010). Impaired holistic processing of unfamiliar individual faces in acquired prosopagnosia. *Neuropsychologia*,*48*(4), 933-944.

Ramon, M., Miellet, S., Dzieciol, A.M., Konrad, B.N., Dresler, M., & Caldara, R. (in press). Super-Memorizers are not Super-Recognizers. *PloSone.*

Ramon, M., & Rossion, B. (2010). Impaired processing of relative distances between features and of the eye region in acquired prosopagnosia—Two sides of the same holistic coin?. *Cortex*, *46*(3), 374-389.

Rezlescu, C., Pitcher, D., & Duchaine, B. (2012). Acquired prosopagnosia with spared within-class object recognition but impaired recognition of degraded basic-level objects. *Cognitive Neuropsychology*, *29*(4), 325-347.

Richler, J. J., Cheung, O. S., & Gauthier, I. (2011). Holistic processing predicts face recognition. *Psychological Science*, *22*(4), 464-471.

Richler, J. J., Floyd, R. J., & Gauthier, I. (2015). About-face on face recognition ability and holistic processing. *Journal of Vision*, *15*(9), 15.

Richler, J. J., & Gauthier, I. (2013). When intuition fails to align with data: A reply to Rossion (2013). *Visual cognition*, *21*(2), 254-276.

Richler, J. J., & Gauthier, I. (2014). A meta-analysis and review of holistic face processing. *Psychological Bulletin*, *140*(5), 1281.

Richler, J. J., Mack, M. L., Palmeri, T. J., & Gauthier, I. (2011). Inverted faces are (eventually) processed holistically. *Vision Research*, *51*(3), 333-342.

Robbins, R., & McKone, E. (2007). No face-like processing for objects-of-expertise in three behavioural tasks. *Cognition*, *103*(1), 34-79.

Robbins, R. A., Shergill, Y., Maurer, D., & Lewis, T. L. (2011). Development of sensitivity to spacing versus feature changes in pictures of houses: Evidence for slow development of a general spacing detection mechanism? *Journal of Experimental Child Psychology*, *109*(3), 371-382.

Rossion, B. (2013). The composite face illusion: A whole window into our understanding of holistic face perception. *Visual Cognition*, *21*(2), 139-253.

Russell, R., Chatterjee, G., & Nakayama, K. (2012). Developmental prosopagnosia and super-recognition: No special role for surface reflectance processing. *Neuropsychologia*, *50*(2), 334-340.

Rossion, B. (2014). Understanding face perception by means of human electrophysiology. *Trends in cognitive sciences*, 18(6), 310-318.

Russell, R., Duchaine, B., & Nakayama, K. (2009). Super-recognisers: People with extraordinary face recognition ability. *Psychonomic Bulletin & Review*, *16*(2), 252-257.

Savran, A., Alyüz, N., Dibeklioğlu, H., Çeliktutan, O., Gökberk, B., Sankur, B., & Akarun, L. (2008). *Bosphorus database for 3D face analysis*. In Biometrics and Identity Management (pp. 47-56). Springer Berlin Heidelberg.

Schmalzl, L., Palermo, R., & Coltheart, M. (2008). Cognitive heterogeneity in genetically based prosopagnosia: A family study. *Journal of Neuropsychology*,*2*(1), 99-117.

Sekiguchi, T. (2011). Individual differences in face memory and eye fixation patterns during face learning. *Acta Psychologica*, *137*(1), 1-9.

Susilo, T., & Duchaine, B. (2013). Advances in developmental prosopagnosia research. *Current Opinion in Neurobiology*, *23*(3), 423-429.

Susilo, T., McKone, E., Dennett, H., Darke, H., Palermo, R., Hall, A., ... & Rhodes, G. (2010). Face recognition impairments despite normal holistic processing and face space coding: Evidence from a case of developmental prosopagnosia. *Cognitive Neuropsychology*, *27*(8), 636-664.

Thomas, A. L., Lawler, K., Olson, I. R., & Aguirre, G. K. (2008). The Philadelphia face perception battery. *Archives of Clinical Neuropsychology*,*23*(2), 175-187.

Townsend, J.T., & Ashby, F.G. (1978). Methods of modeling capacity in simple processing systems. In J. Castellan & F. Restle (Eds.), Cognitive theory. Vol. 3. (pp. 200-239). Hillsdale, N.J.: Erlbaum.

Townsend, J.T., & Ashby, F.G. (1983). Stochastic modeling of elementary psychological processes. Cambridge: Cambridge University Press.

Valentine, T. (1988). Upside- down faces: A review of the effect of inversion upon face recognition. *British Journal of Psychology*, *79*(4), 471-491.

Van Belle, G., Lefèvre, P., & Rossion, B. (2015). Face inversion and acquired prosopagnosia reduce the size of the perceptual field of view. *Cognition, 136*, 403-408.

Wang, R., Li, J., Fang, H., Tian, M., & Liu, J. (2012). Individual differences in holistic processing predict face recognition ability. *Psychological Science*, *23*(2), 169-177.

Wechsler, D. (2011). *Wechsler Abbreviated Scale of Intelligence–Second Edition (WASI-II).* San Antonio, TX: NCS Pearson.

Wilmer, J. B., Germine, L., Chabris, C. F., Chatterjee, G., Williams, M., Loken, E., ... & Duchaine, B. (2010). Human face recognition ability is specific and highly heritable. *Proceedings of the National Academy of Sciences*, *107*(11), 5238-5241.

Wilmer, J. B., Germine, L., Chabris, C. F., Chatterjee, G., Gerbasi, M., & Nakayama, K. (2012). Capturing specific abilities as a window into human individuality: the example of face recognition. *Cognitive Neuropsychology*, *29*(5-6), 360-392.

Young, A. W., Hellawell, D., & Hay, D. C. (1987). Configurational information in face perception. *Perception*, *16*(6), 747-759.

Yovel, G., & Kanwisher, N. (2008). The representations of spacing and part-based information are associated for upright faces but dissociated for objects: Evidence from individual differences. *Psychonomic Bulletin & Review*, *15*(5), 933-939.

Zhu, Q., Song, Y., Hu, S., Li, X., Tian, M., Zhen, Z., ... & Liu, J. (2010). Heritability of the specific cognitive ability of face perception. *Current Biology*,*20*(2), 137-142.

Table 1. Demographical and background neuropsychological information about the SR participants, presented in comparison to controls. Values for the performance of the SR participants on the CFMT+ are expressed in the number of SDs away from the control mean.

	Controls			Super-Recognisers					
	Mean	SD	N	CH	DF	JN	GK	CW	TP
Age	32.10	9.30	30	27	18	35	33	21	35
Gender	19 (F)	-	30	M	M	F	M	M	M
Handedness	3L	-	30	R	R	R	R	R	R
WASI-II[a]:									
Verbal	-	-	-	148	114	99	118	-	127
Performance	-	-	-	111	131	116	119	-	127
Full-2 IQ	-	-	-	134	125	108	121	-	130
WTAR[b]	113.80	8.20	30	-	-	-	-	115	-
CFMT+[c]	68.4/102	11.70	30	2.40*	2.40*	2.40*	2.70*	2.70*	2

* indicates participant significantly differed to controls using Crawford et al.'s (2010) modified *t*-tests for single-case comparisons ($p < .05$)

[a]Wechsler Abbreviated Scale of Intelligence, Second Edition (Wechsler, 2011) – this more thorough assessment of IQ was carried out with available SRs; [b]Wechsler Test of Adult Reading (Wechsler, 2001) – this quick IQ screen was used with controls to ensure they were appropriately matched to the SRs and with CW due to time constraints; [c]Cambridge Face Memory Test - Long Form (Russell et al., 2009) – this test was used to confirm superior face recognition skills in the SRs and typical skills in the controls.

Table 2. Results from the object-processing tasks administered in Study 1. All values for SR participants are expressed in the number of SDs away from the control mean.

	Controls			Super-Recognisers					
	Mean	SD	N	CH	DF	JN	GK	CW	TP
Matching test (d'):									
Faces upright	2	0.40	21	1.60	2.90*	3.30*	0.10	1.10	1.80
Faces inverted	1	0.60	21	0.40	-0.50	-0.70	-0.50	-0.80	-0.60
Face inversion effect	1.04	0.61	21	1.56	2.51*	3.03*	0.56	1.62	1.82
Hands upright	2	0.70	21	1.60	-0.40	0.50	1.10	0.10	-0.10
Hands inverted	1.90	0.60	21	0.40	0.70	0.90	2.20*	-1.10	-0.30
Hand inversion effect	0.10	0.46	21	2.67*	-1.35	-0.39	-1.04	1.37	0.17
Houses upright	2.80	0.60	21	-1.20	0	0.20	0.70	-1.80	1
Houses inverted	2.60	0.70	21	-1.90	0.20	0.30	-4.40*	-0.30	1
House inversion effect	0.20	0.51	21	-1.37	-0.31	-0.24	7.14*	-1.71	-0.29
CCMT[a]:									
Females	50.40/72	7.20	93	-	-	0.60	-	-	-
Males	57.40/72	8.30	60	0.20	0.90	-	-0.70	0.40	1.60

* indicates participant significantly differed to controls using Crawford et al.'s (2010) modified *t*-tests for single-case comparisons ($p < .05$)

[a]Cambridge Car Memory Test (test and norms from Dennett et al., 2012) – performance varies according to gender on this test.

Table 3. Results from the CFPT administered in Study 2. All values for SR participants are expressed in the number of SDs away from the control mean.

	Controls			Super-Recognisers					
	Mean	SD	N	CH	DF	JN	GK	CW	TP
Perception of facial identity									
Matching test (upright faces, d'):	2	0.40	21	1.60	2.90*	3.30*	0.10	1.10	1.80
CFPT[a]:									
Upright	35.90	15	58	-0.70	-1.60	-1.10	-1.30	-1.30	-1.10
Inverted	61.80	11.40	58	0.60	-1.20	0.20	-1.60	-0.30	-1.70

* indicates participant significantly differed to controls using Crawford et al.'s (2010) modified *t*-tests for single-case comparisons ($p < .05$)

[a]Cambridge Face Perception Test (Duchaine et al., 2007), lower score indicates better performance;

Table 4. Results from the holistic processing tests described in Study 3. All values for SR participants are expressed in the number of SDs away from the control mean.

	Controls			Super-Recognisers					
	Mean	SD	N	CH	DF	JN	GK	CW	TP
Navon task (global bias index [a])	0.90	0.10	28	0.50	0.60	-2.80*	0.50	0.70	-0.10
CFPT (inversion index [b])	1	0.80	58	2	3*	2.20	1.90	2.70*	1.10
Matching test (faces inversion effect [c])	1	0.60	21	1.60	2.50*	3*	0.60	1.60	1.80
Composite task (composite effect [d]):									
Faces upright	314.40	368.10	29	-0.70	0	0.5	-0.70	-0.70	2.50*
Faces inverted	3.40	213.50	29	-0.20	0	0.10	0.60	-2.00	0.10
Dogs upright	-24.00	164.21	29	-0.46	1.89	-0.88	1.58	-0.84	-2.24
Dogs inverted	-38.10	173.83	29	0.94	0.40	-0.81	-0.87	-1.14	2.41

* indicates participant significantly differed to controls using Crawford et al.'s (2010) modified *t*-tests for single-case comparisons ($p < .05$)

[a]Test from Navon (1977), global bias index from Duchaine et al. (2007); [b]Inversion index = (upright-inverted)/upright (calculated using total errors in the upright and inverted condition; Russell et al., 2009) ; [c]Inversion effect = d' (upright) – d' inverted; [d]Composite effect = IE(aligned) – IE(misaligned) (Robbins & McKone, 2007).

Table 5. The overall pattern of performance noted for each of the six SR participants. A tick refers to cases where a significant enhancement occurred on at least one test, and “T” to a non-significant trend, classed as performance above 1.8 standard deviations from the control mean.

	Super-Recognisers					
	CH	DF	JN	GK	CW	TP
Facial identity recognition	✓	✓	✓	✓	✓	✓
Object-processing				✓		✓
Facial identity perception		✓	✓			T
General global processing bias			✓			
Face-specific configural/holistic processing	T	✓	✓	T	✓	✓

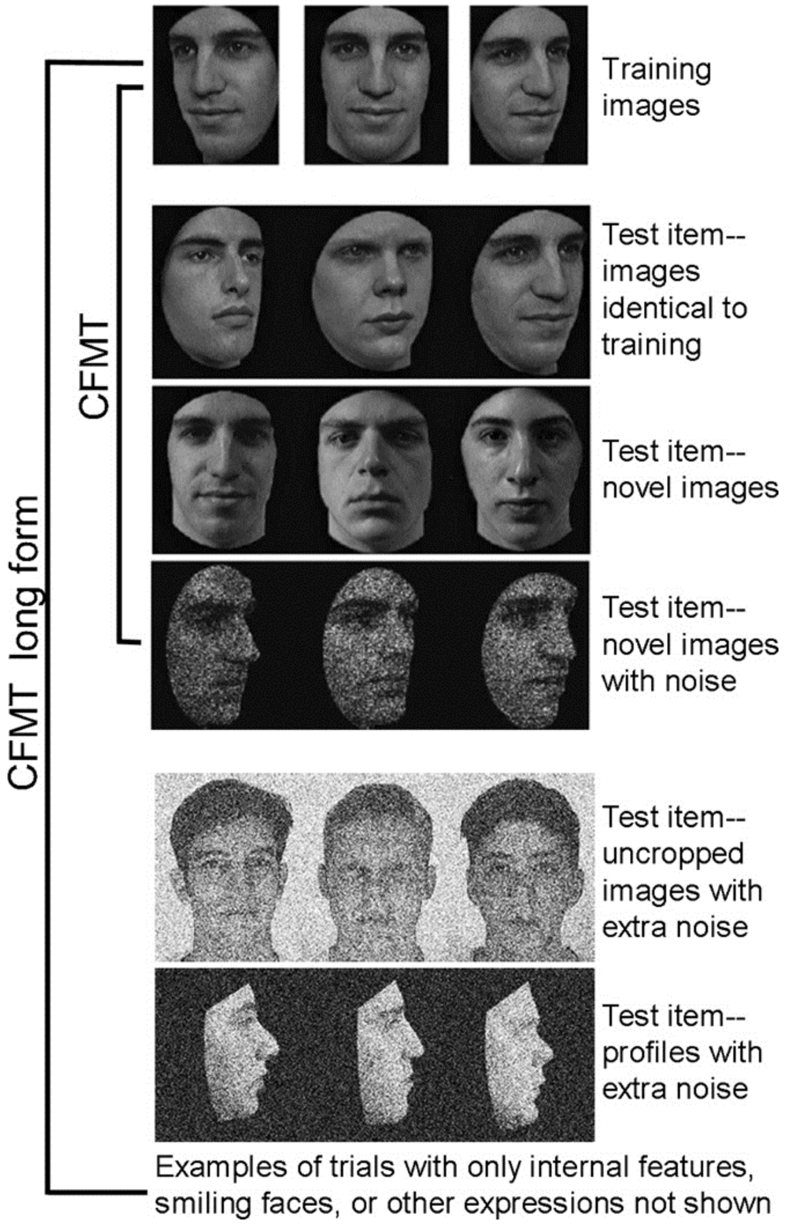

Figure 1. The structure of the CFMT+ (Russell et al., 2009).

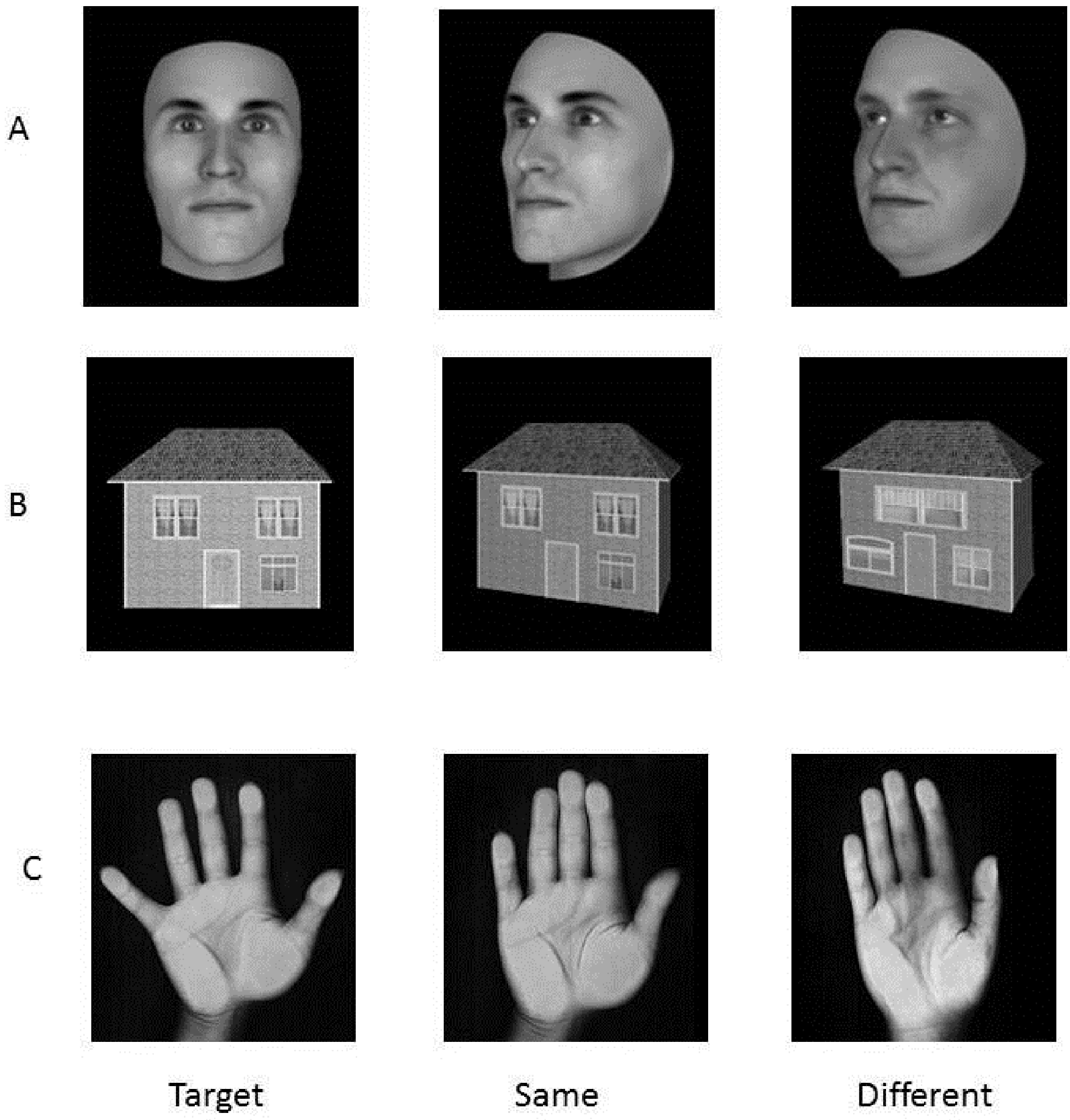

Figure 2. Sample stimuli from the object matching task: (A) faces, (B) houses and (C) hands. In the hands stimuli, finger splay rather than orientation differed between exemplars. Face images shown in this figure are computer-generated and for illustration only. The stimuli that were actually used in the test were of real faces, but publication rights cannot be obtained.