

**Onset complexity and task conflict in the Stroop task**

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3 Onset complexity and task conflict in the Stroop task  
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## Abstract

The present study examined the extent to which a key marker of task conflict, negative facilitation, is modified by *onset complexity*. Negative facilitation, slower RTs to congruent stimuli than to non-lexical neutral stimuli in the Stroop task, is thought to reflect competition between the task sets of colour naming and word reading in the Stroop task (also known as task conflict). That is, it reflects competition between whole task sets, over and above any competition between specific responses associated with a stimulus. An alternative account of negative facilitation argues that it reflects the specific phonological processing differences between pronounceable (e.g., congruent) and non-pronounceable (e.g., xxxx) stimuli that are magnified by the specific task contexts that produce negative facilitation (a mostly non-lexical trial context). Here we used *onset complexity* to manipulate pronounceability of the irrelevant words in the Stroop task to test this alternative account. However, before applying manipulations that produce negative facilitation, we initially tested whether there was an effect of onset complexity on Stroop task performance. The results from Experiment 1 (and 3) showed that complex onsets led to larger positive facilitation and congruency effects relative to simple onsets, but did not modify incongruent or neutral word RTs. Experiment 2 directly tested whether onset complexity modifies negative facilitation and provided strong evidence for no effect of onset complexity, contrary to the alternative account predictions. The implications of the results for task conflict theory, selective attention and phonological processing in the manual response Stroop task are discussed.

**Keywords:** Task set, Stroop task, Onset, Manual response

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3 The Stroop task (Stroop, 1935) requires participants to focus on one dimension of a stimulus,  
4 the colour dimension, whilst ignoring another dimension, the word dimension. The task  
5 produces the Stroop *interference* effect – referring to the fact that identifying the colour that a  
6 word is printed in takes longer when the word denotes a different colour (colour-incongruent  
7 trials; e.g., the word *red* displayed in blue font) compared to a comparison baseline (e.g., the  
8 colour-neutral word *top* displayed in blue font). In addition, words that are congruent with the  
9 colour (colour-congruent trials; e.g., the word *red* in red font) commonly result in faster  
10 colour-identification times when compared to a colour-neutral baseline condition, producing  
11 the Stroop *facilitation* effect (Dalrymple-Alford, 1972; Dalrymple-Alford & Budayr, 1966;  
12 see MacLeod, 1991, and Parris et al., 2022, for a review).

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14  
15 For most of their history, the magnitudes of Stroop interference and Stroop facilitation  
16 were thought to result solely from the information conveyed by the irrelevant word  
17 dimension. That is, the extent to which phonological, semantic, or response information in  
18 the irrelevant dimension differed (together referred to as *informational* conflict) or was  
19 consistent with that in the relevant dimension was thought to determine the magnitude of  
20 Stroop interference and facilitation, respectively (Hasshim & Parris, 2014; 2021; MacLeod,  
21 1991; Parris et al., 2022). However, more recent work has attributed some of Stroop task  
22 performance to an additional competition between whole task sets, a form of conflict referred  
23 to as *task* conflict (MacLeod & MacDonald, 2000; Monsell et al., 2001). That is, competition  
24 between the endogenously activated task set for colour naming and the exogenously activated  
25 task set for word reading; a form of task set conflict akin to that observed in task switching  
26 studies (Monsell, 2003; Rogers & Monsell, 1995). In line with this idea, several lines of  
27 research have attempted to measure task conflict independently of informational conflict (see  
28 Littman et al., 2019 and Parris et al., 2022, for reviews).

29 For task conflict to occur, at least two task sets must compete for activation. This  
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3 means that the entire collection of control settings / task parameters that program the system  
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5 to perform one task (e.g., word reading – consisting of visual analysis, letter/grapheme  
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7 identification, lexical identification (semantic processing), phonological processing) would  
8  
9 compete for activation with the entire collection of control settings that program the system to  
10  
11 perform another task (e.g., classify a colour – consisting of visual analysis, colour  
12  
13 identification, semantic processing, phonetic encoding). The idea is that “whole task sets  
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15 compete, over and above any competition between specific responses associated with a  
16  
17 stimulus” (Monsell et al., 2001, pp. 139-140). That is, in addition to and over and above any  
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19 stimulus-response associations. In the context of the Stroop task, three findings have been  
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21 interpreted as evidence for “task conflict”: 1) Anterior cingulate activation on congruent trials  
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23 (MacLeod & McDonald, 2000); 2) slower colour-naming responses to neutral words (e.g., the  
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25 word ‘house’) than to non-lexical (i.e., non-pronounceable) stimuli (e.g., ‘xxxx’; see  
26  
27 Augustinova, Parris & Ferrand, 2019); 3) slower responses to congruent stimuli than to non-  
28  
29 lexical stimuli, also known as reverse or negative facilitation (e.g., Goldfarb & Henik, 2007).  
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31 In the present study, we focus on the latter.  
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38 Indeed, to measure task conflict in the Stroop task, studies have often compared  
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40 performance on trials on which the irrelevant dimension is a word (e.g., a colour word) to  
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42 trials on which the irrelevant dimension is non-lexical (e.g., a sequence of repeated letters  
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44 such as xxxx or www; e.g., Goldfarb & Henik, 2007). Since congruent stimuli contain  
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46 words (e.g., the word red in red) they should involve task conflict whereas non-lexical stimuli  
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48 should not, meaning that colour naming responses should be longer for stimuli that have  
49  
50 irrelevant real words than those that have irrelevant non-lexical stimuli. However, when  
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52 comparing congruent and repeated-letter string trials, congruent trials are commonly  
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54 responded to more quickly, producing positive, not negative facilitation (e.g., Brown, 2011;  
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56 Klein, 1964; Monsell et al., 2001), which might represent a challenge to the task conflict  
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3 account. Goldfarb and Henik (2007) reasoned that this is because in most Stroop tasks there  
4 is a sufficiently large proportion of lexical stimuli to activate task conflict control. In other  
5 words, constant exposure to real words in the Stroop task puts the *task conflict controller* on  
6 high alert, ensuring that it is active, and that task conflict is kept low. The activation of task  
7 conflict control means that positive facilitation can be expressed in the RT data. Goldfarb and  
8 Henik (2007) further reasoned that increasing the proportion of non-lexical neutral trials (e.g.,  
9 repeated letter strings) would create the expectation for a low task conflict context, thereby  
10 reducing task conflict control. This would result in the exposure of task conflict via its unique  
11 behavioural expression, *negative facilitation, where congruent stimuli are responded to more*  
12 *slowly than repeated-letter stimuli*. The results from their Experiment 1 supported this  
13 prediction (see also e.g., Entel & Tzelgov, 2018; 2020; Entel et al., 2015; Kalanthroff et al.,  
14 2015).

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16  
17 In a subsequent experiment Goldfarb and Henik (2007, Experiment 2) replaced  
18 repeated-letter trials with neutral word trials (i.e., the Hebrew word for *building*) and showed  
19 that negative facilitation was now absent. Thus, they not only reported negative facilitation  
20 for the first time, but they also showed its extinction. As a result, they introduced the notion  
21 of a task conflict controller, a part of a system of cognitive control that is deployed to reduce  
22 or prevent task conflict (see also Kalanthroff et al., 2018; and Littman et al., 2019, for a mini  
23 review). Also, and importantly, this line of research has provided insights into the nature of  
24 selective attention and has given rise to a new potential form of impairment that might  
25 explain symptoms of clinical disorders such as obsessive-compulsive disorder (OCD;  
26 Kalanthroff et al., 2017).

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29 Recently, however, the extent to which task sets and their control determine cognitive  
30 performance has been questioned. In the context of task switching, some of the processing  
31 costs that were previously attributed to controlled switching between active task sets, have  
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3 been accounted for with reference to feature-integration biases (see Schmidt et al., 2020).  
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5 Subsequently, Parris et al. (2023) described current challenges to the task conflict account of  
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7 negative facilitation in selective attention tasks. They pointed out that some of the findings  
8  
9 that were foundational in terms of the original conceptualisation of task conflict have not  
10  
11 been subsequently strongly supported and argued that the mechanisms that lead to negative  
12  
13 facilitation are not well-understood. In an attempt to highlight the notion that other accounts  
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15 of the data are at least feasible, Parris et al. (2023) also presented a tentative alternative  
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17 account of negative facilitation. In essence, the alternative account argued that contrary to  
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19 Monsell et al.'s (2001) position that “whole task sets compete, over and above any  
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21 competition between specific responses associated with a stimulus” (Monsell et al., 2001:  
22  
23 139-140), it is in fact competition between the specific phonological / phonetic responses  
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25 associated with pronounceable irrelevant stimuli and relevant colour names, that leads to  
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27 negative facilitation (see Parris et al., 2023, Figure 1); competition that is increased by  
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29 reduced control over word reading induced by the mostly non-lexical trial context.  
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### 38 **An alternative account of negative facilitation**

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40 Parris et al. (2023) pointed out that the observance of negative facilitation is determined by  
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42 whether the baseline condition is non-lexical (e.g., repeated-letter strings) or lexical (colour-  
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44 neutral words). Task conflict proponents argue that the difference between these two types of  
45  
46 stimuli is the presence of task conflict on neutral word trials and its absence on repeated-letter  
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48 trials (hence their large proportion puts the task controller on low alert). Indeed, some  
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50 researchers (including ourselves) have even used the difference in RTs between these two  
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52 types of stimuli as a measure of task conflict (Augustinova et al., 2018; Augustinova et al.,  
53  
54 2019; Ferrand et al., 2020; Kinoshita et al., 2017; Kinoshita et al., 2018). However, Parris et  
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56 al. (2023) argued these stimuli also differ in *pronounceability*. Recent work indicates that  
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3 pronounceable letter strings result in the sub-lexically generated phonology which then  
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5 interferes with the segment-to-frame association processing in articulation planning, also  
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7 known as phonological encoding (Kinoshita et al., 2017). Given that repeated-letter Stroop  
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9 trials are free of this pronounceability cost, they might be responded to faster than congruent  
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11 Stroop trials, which are burdened by the pronounceability cost, thereby producing negative  
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13 facilitation (see Figure 1 for a visual representation of the two accounts of negative  
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15 facilitation). Under this account, negative facilitation is not due to the fact that a large portion  
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17 of repeated letter string trials puts the task conflict controller on low alert allowing the  
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19 expression of task conflict. Rather, a large portion of repeated letter string trials reduces  
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21 control over word reading and enhances the pronounceability cost of the infrequently  
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23 presented pronounceable items, including congruent stimuli, to the point that congruent items  
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25 are responded to slower than items that are free of pronounceability cost. Of course, if the  
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27 pronounceability cost is accentuated, why would the pronounceability benefit offered by  
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29 congruent trials not also be accentuated, producing more positive facilitation? Parris et al.  
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31 (2023) pointed out that having a large proportion of neutral trials in the Stroop task, whether  
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33 they be neutral words, repeated-letter strings, or shapes, has consistently resulted in the  
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35 absence of positive facilitation. In other words, there is something about a mostly neutral trial  
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37 context that prevents positive facilitation (see the General Discussion for a fuller discussion  
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39 of this issue). Thus, the conditions of the experiment remove the congruency benefit and  
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41 congruent words become equivalent to neutral words. Under this account there is no need for  
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43 a task controller and instead the burden of control falls to the controller that is already  
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45 responsible for reducing the impact of the phonetic code of the irrelevant stimulus during  
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47 Stroop task performance.

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49 A prediction that follows from this alternative account is that any factor that modifies  
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51 the pronounceability cost will modify negative facilitation. Therefore, the present study  
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3 examined the extent to which negative facilitation is modified by pronounceability, using  
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5 *onset complexity* to manipulate pronounceability. Initially we investigated whether there was  
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7 an effect of onset complexity on Stroop task performance in a mostly neutral word trial  
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9 context. We then changed the mostly neutral word context to a mostly non-lexical, repeated-  
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11 letter trial context which was expected to induce negative facilitation.  
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### 17 **Onset complexity**

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19 The onset of a word is the initial phonological unit which contains the initial consonant or  
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21 blend of consonants. Simple onsets are those that consist of a single consonant followed by a  
22  
23 vowel. The colour words *red* and *purple* are examples of colour words that have a simple  
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25 onset. Complex onsets are those that consist of two or more consonants. The colour words  
26  
27 *blue* and *green* have complex onsets.  
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31 Onset complexity has been shown to affect word reading latency. For example,  
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33 Frederiksen and Kroll (1976) reported that words with complex onsets are read aloud more  
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35 slowly than words with simple onsets. However, Kawamoto and Kello (1999) reported that  
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37 words with complex onsets are read aloud more quickly than are words with simple onsets –  
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39 exactly the opposite result. Kawamoto and Kello hypothesized that the inconsistency in their  
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41 results was due to how response latency was measured. Rastle and Davis (2002) replicated  
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43 Kawamoto and Kello's (1999) results when response latency was based on hand-marking  
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45 digitized responses, but reported an opposite effect when a simple voice-key was used,  
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47 replicating Frederiksen and Kroll (1976). Moreover, Rastle and Davis (2002) reported no  
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49 effect of onset complexity when an integrator voice-key was used. These results suggest that  
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51 the effect of onset complexity on word reading latency can be determined by how acoustic  
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53 latency is measured (Rastle & Davis, 2002; see also Kinoshita, 2000 vs. Schiller, 2008; for  
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55 contrasting effects of onset complexity in the masked onset priming effect). However, given  
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3 the clear benefits of visually inspecting the acoustic waveform and hand-marking onsets, the  
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5 best evidence to date suggests a complexity benefit (words with complex onsets are read  
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7 more quickly than those with simple onsets; ~9ms in Rastle & Davis, 2002 and ~5ms in  
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9 Kawamoto & Kello, 1999). Nevertheless, it is noteworthy that in the Stroop task, the word is  
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11 not actually read aloud. Instead, a colour is named aloud, as in the vocal Stroop task, or it is  
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13 classified by button-press, as in the manual Stroop task. This permits consideration of onset  
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15 complexity without the attendant issues associated with measuring acoustic latency.  
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19 It is further worth noting that an effect of onset complexity on word naming latencies  
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21 in either direction have associated accounts: longer RTs for complex onsets have been  
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23 accounted for by the notion of a longer activation for the first phoneme of a complex onset  
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25 than for the single phoneme in a simple onset (McKay, 1987). Shorter latencies for complex  
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27 onsets have been accounted for by the notion of there being a larger number of competitor  
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29 words at the initial phoneme position (O'Seaghdha et al., 1992; Taraban & McClelland,  
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31 1987) for simple onset stimuli (e.g., *sand* would have neighbours *band, hand, land, wand*) –  
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33 here complexity is beneficial. Nevertheless, what is important for the purposes of the present  
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35 experiments is that both accounts are based on the notion that the effect of onset complexity  
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37 occurs at the stage at which the pronunciation is determined (Kawamoto & Kello, 1999).  
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39 Therefore, in line with our initial reasoning about pronounceability cost in the Stroop task  
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41 (see Parris et al., 2023) it remains plausible that onset complexity also determines the amount  
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43 of this cost. As far as we are aware, no study has yet investigated this type of effect (but see  
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45 Berent & Marom, 2005, who showed a skeletal congruency effect in the Stroop task which  
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47 reflected the overlap of phonological frames between word and colour name). Thus, the aim  
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49 of the present study was to fill this void and to investigate whether there is an onset  
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51 complexity effect in the Stroop task (Experiment 1) before going on to explore the effect of  
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53 onset complexity on negative facilitation (Experiment 2). To be clear, the alternative account  
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3 does not predict that either simple or complex onsets are the sole cause of negative  
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5 facilitation; if onset complexity modifies performance, negative facilitation will be bigger in  
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7 one condition than in the other, but it should be present in both because relative to a non-  
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9 pronounceable baseline, pronounceable stimuli will incur a processing cost.  
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### 14 **Experiment 1**

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16 The aim of the present experiment was to investigate how onset complexity affects  
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18 Stroop task performance. To investigate this issue initially and independently of factors  
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20 thought to induce task conflict, the present experiment employed a mostly neutral word  
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22 context (see Goldfrab & Henik, 2007, Experiment 2). Since recent evidence indicates that  
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24 phonological processing does occur with manual responses (Parris et al., 2019; but see  
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26 Kinoshita et al., 2017; Kinoshita & Mills, 2020), the participants used manual key-presses to  
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28 identify the colour of different Stroop stimuli. The irrelevant dimension of these stimuli  
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30 consisted of irrelevant colour words with simple (i.e., red and purple) and complex (i.e., blue  
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32 and green) onsets. The onset complexity of colour-neutral words was further manipulated  
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34 such that words with complex (e.g., dry) and simple (e.g., dog) onsets were used. If onset  
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36 complexity affects pronunciation of any letter string, a difference will be observed between  
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38 the neutral trials with simple vs. complex onsets. If, on the other hand, the locus of the onset  
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40 complexity effect is at the level of activation of competitor responses (i.e., affects  
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42 informational conflict), onset complexity will interact with Stroop effects. In the present  
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44 experiment we also employed two different sets of Complex Neutral and Simple Neutral  
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46 words to avoid observed effects being due specifically to the choice of neutral words. Half  
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48 the participants were exposed to one set, half to the other.  
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## Method

### *Design*

4 (Word Type: Incongruent vs. Congruent vs. Neutral Complex vs. Neutral Simple) x 2 (Onsets: Complex vs. Simple) repeated-measures design with reaction times as the dependent variable.

### *Participants*

Following Brysbaert and Stevens' (2018) recommendation for at least 1600 trials per condition, in both experiments presented in this paper we aimed to initially recruit at least 67 participants. Moreover, test sensitivity of the interactions and main effects were assessed through Bayes Factors and the optional stopping rule was applied for interactions (Rouder, 2014) after the initial 67 were recruited with the maximum number of participants limited to 90 participants given the funds available. In total 76 participants were recruited through the online testing platform, Testable (testable.org). Participants had to fulfil the following criteria to participate: 1) Be a Verified Mind; 2) Have an approval rate above 95%; 3) Be at least 18 years of age and below the age of 60; 4) Have English as their first language (British or American); 5) Could not have participated in previous Stroop studies run on the host account. It was also requested that the Testable Minds platform matched the number of male and female participants. All participants were paid \$4.50. Of the 75 participants, 4 were removed for reporting a language other than English as their first language, and 3 were removed for having >70% errors in any one of the experimental conditions. Of the remaining 69 participants, 36 were male. The ages ranged from 19-60 with an average age of 31.9 years (standard deviation = 10.3).

### *Stimuli and Procedure*

The colours red (RGB: 255,0,0), purple (RGB: 128,0,128), green (RGB: 0,128,0) and blue (RGB: 0,0,255) were used as the response colours. These colours were chosen because the

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3 names *red* and *purple* have simple onsets, whilst *green* and *blue* have complex onsets and the  
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5 two onset types were matched for word length (average 4.5 letters for both). The neutral  
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7 words were matched to the colour words on the following dimensions: 1) number of letters;  
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9  
10 2) number of phonemes; 3) number of syllables. Complex graphemes such as ‘ph’ ‘sh’ (two  
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12 letters but one phoneme) and onsets with the first letters of the colour names R/B/G/P were  
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14 avoided for the neutral stimuli. There were two types of neutral stimuli; for complex onset  
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16 colour words there were both complex and simple onset neutral stimuli. Similarly, for the  
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18 simple onset colour words there were both complex and simple onset neutral stimuli. A  
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20 comparison of the two types of neutral words that are matched on psycholinguistic variables  
21  
22 permits measurement of potential onset complexity effects for neutral words. The complex  
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24 onset neutral words matched to the complex onset colours blue and green were *crew* and  
25  
26 *train* (Complex Neutrals for Complex or CNC) and the simple onset neutral words were *cake*  
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28 and *taste* (Simple Neutrals for Complex or SNC). Similarly, for the simple onset colour  
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30 words there were both complex and simple onset neutral stimuli. The complex onset neutral  
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32 words matched to the simple onset colours red and purple were *dry* and *frozen* (heretofore  
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34 Complex Neutrals for Simple or CNS) and the simple onset neutral words were *dog* and  
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36 *farmer* (Simple Neutrals for Simple or SNS; see Table 1 for the lexical characteristics of the  
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38 stimuli used in Experiment 1).  
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45 Furthermore, a second set of neutral stimuli were employed to avoid any observed  
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47 effects being due to the phonological characteristics of the onsets. In the second set, the CNS  
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49 words were *fly* and *clever* and the SNS words were *far* and *carbon*. The CNC words were  
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51 *tree* and *floor* and the SNC words were *tape* and *force*.  
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55 Once participants clicked the link to the experiment, they were directed to a reCaptcha  
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57 challenge. Once completed, participants calibrated their screen to ensure all stimuli were  
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59 presented the same size for all participants. Participants were then asked to enter their age,  
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3 gender, nationality and first language. They were then presented with instructions asking  
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5 them to respond as quickly and as accurately as they could to the colour of the font of the  
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7 letter string presented at the screen's centre. On each trial a fixation cross was presented for  
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9 2000ms before the onset of the Stroop stimulus. The Stroop stimuli stayed on the screen until  
10  
11 a response was made or until 2000ms had elapsed. Participants responded using the c (blue),  
12  
13 b (purple), n (green) and v (red) keys on their keyboards. Incorrect responses resulted in  
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15 feedback showing a large X (size +5 in Testable) which was presented for 500ms.  
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18 There were 384 trials in total. Forty-eight of the trials were incongruent, 48 were congruent.  
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20 Of the 48 incongruent trials, 24 had complex onset, 24 had simple onsets; likewise for the  
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22 congruent items. Of the 288 neutral word stimuli, 144 had simple onsets and 144 had  
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24 complex onsets. Of the 144 simple onset neutral trials, 72 were matched to the complex onset  
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26 colour words and 72 were matched to the simple onset colour words. Similarly, of the 144  
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28 complex onset neutral trials, 72 were matched to the complex onset colour words and 72 were  
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30 matched to the simple onset colour words (see Table 2 for a Stimulus Matrix for Experiments  
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32 1 - 3). Again, having the two types of neutral words matched to both the complex and simple  
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34 onset colour words meant that we could compare RTs to matched neutral words that differed  
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36 in onset complexity but were matched on other psycholinguistic variables.  
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42 --- Insert Table 1 about here ---

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## 49 **Results**

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51 Only data from correct trials are reported below since there were no effects in the error data  
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53 other than main effects of Word Type (7.1% of data were removed as errors – see Table 3 for  
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55 error percentages as a function of condition). Any RTs greater than 2SDs either side of the  
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3 overall mean were removed from analysis resulting in the removal of 2.8% of the correct  
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5 trials.  
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8 The data were entered into a 4 (Word Type: Incongruent vs. Complex Neutral vs.  
9  
10 Simple Neutral vs. Congruent) x 2 (Onsets: Complex vs. Simple) repeated-measures  
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12 ANOVA and its Bayesian equivalent (see Figure 1; and see Table 3 for means, percentage  
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14 errors and Stroop effects). These analyses revealed a main effect of Word Type [ $F(1.844,$   
15  
16  $125.389)$ , Greenhouse-Geisser = 79.561,  $p < .001$ ,  $\eta^2 = .381$ ,  $BF_{10} = 7.22 \cdot 10^{30}$ ] but no main  
17  
18 effect of Onset [ $F(1, 68) = 1.138$ ,  $p = .290$ ,  $BF_{01} = 6.255$ ]. However, the interaction between  
19  
20 Word Type and Onsets was significant [ $F(2.246, 152.704)$ , Greenhouse-Geisser, = 6.667,  $p =$   
21  
22  $.001$ ,  $\eta^2 = .021$ ] with  $BF_{incl} = 143$  for just the interaction (i.e., without the main effects also  
23  
24 included in the model).  
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29 The interaction was further decomposed into two one-way repeated-measures  
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31 ANOVAs and their Bayesian equivalents investigating Stroop effects in the Complex Onset  
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33 and Simple Onset conditions independently. A significant ANOVA for the Complex Onset  
34  
35 stimuli [ $F(3, 204) = 62.883$ ,  $p < .001$ ,  $\eta^2 = .480$ ,  $BF_{10} = 3.27 \cdot 10^{25}$ ] was underpinned by a  
36  
37 significant overall Stroop or congruency effect (i.e., mean difference between Congruent and  
38  
39 Incongruent trials) of 119ms [ $t(68) = 12.682$ ;  $p(\text{Holm}) < .001$ ,  $d = 0.930$ ,  $BF_{10} = 3.56 \cdot 10^{11}$ ].  
40  
41 This latter effect resulted from a significant positive facilitation of 28ms [ $t(68) = 2.985$ ,  
42  
43  $p(\text{Holm}) = .010$ ,  $d = .711$ ,  $BF_{10} = 23.056$ ] and a significant Stroop interference effect (91ms)  
44  
45 [ $t(68) = 9.697$ ,  $p(\text{Holm}) < .001$ ,  $d = .711$ ,  $BF_{10} = 1.99 \cdot 10^{10}$ ] when CNC stimuli were used as  
46  
47 a color-neutral comparison baseline. When SNC stimuli were used to this end, the  
48  
49 aforementioned congruency effect resulted from significant positive facilitation of 22ms,  
50  
51 [ $t(68) = 2.301$ ,  $p(\text{Holm}) = .045$ ,  $d = .219$ ] albeit where the Bayes Factor was anecdotal,  $BF_{10}$   
52  
53 = 1.85; and a significant Stroop interference effect of 97ms, [ $t(68) = 10.381$ ,  $p(\text{Holm}) <$   
54  
55  $.001$ ,  $d = .761$ ,  $BF_{10} = 7.07 \cdot 10^{11}$ ]. Reaction times to Neutral stimuli with Complex vs. Simple  
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3 onsets did not differ significantly [6ms;  $t(68) = 0.684$ ,  $p(\text{Holm}) = .495$ ] where the Bayes  
4  
5 Factor supported the null,  $\text{BF}_{01} = 3.632$ .

6  
7  
8 A significant ANOVA for the Simple Onset stimuli [ $F(3, 204) = 37.997$ ,  $p < .001$ ,  $\eta^2 =$   
9  
10 .358,  $\text{BF}_{10} = 2.91 \times 10^{16}$ ] was underpinned by a significant Stroop Congruency effect of 72ms  
11  
12 [ $t(68) = 7.820$ ,  $p(\text{Holm}) < .001$ ,  $d = 0.571$ ,  $\text{BF}_{10} = 268861$ ]. This latter effect resulted from a  
13  
14 non-significant negative facilitation [i.e., -7ms;  $t(68) = 0.761$ ,  $p(\text{Holm}) = .775$ ,  $\text{BF}_{10} = 0.204$ ];  
15  
16 and a significant Stroop interference effect of 79ms [ $t(68) = 8.581$ ,  $p(\text{Holm}) < .001$ ,  $d = .626$ ,  
17  
18  $\text{BF}_{10} = 4.46 \times 10^7$ ] when CNS stimuli were used as a color-neutral comparison baseline. When  
19  
20 SNC stimuli were used to this end, the aforementioned congruency effect resulted from a  
21  
22 non-significant negative facilitation [i.e., -15ms;  $t(68) = 1.627$ ,  $p(\text{Holm}) = .316$ ] albeit where  
23  
24 the Bayes Factor was anecdotal,  $\text{BF}_{10} = 0.585$ ]; and a significant Stroop interference effect of  
25  
26 87ms [ $t(68) = 9.446$ ,  $p(\text{Holm}) < .001$ ,  $d = .690$ ,  $\text{BF}_{10} = 1.55 \times 10^9$ ]. Again, reaction times to  
27  
28 Neutral stimuli with Complex vs. Simple onsets did not differ significantly [8ms;  $t(68) =$   
29  
30 0.866,  $p(\text{Holm}) = .775$ ] where the Bayes Factor favoured the null anecdotally,  $\text{BF}_{01} = 2.179$ ].  
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### 38 *Effect of onset complexity on the Stroop Congruency Effect*

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40 To assess the effect onset complexity on the Stroop congruency effect further, the data  
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42 were entered into a 2 (Onsets: Complex vs. Simple) x 2 (Word Type: Congruent vs.  
43  
44 Incongruent) repeated-measures ANOVA and its Bayesian equivalent. These analyses  
45  
46 revealed a significant main effect of Word Type [ $F(1, 68) = 105.631$ ,  $p < .001$ ,  $\eta^2 = .407$ ,  
47  
48  $\text{BF}_{10} = 3.715 \times 10^{12}$ ] and as in previous analyses, no main effect of Onset [ $F(1, 68) = 2.401$ ,  $p$   
49  
50  $= .126$ ,  $\text{BF}_{01} = 3.273$ ]. However, the interaction was also significant [ $F(1, 68) = 9.662$ ,  $p =$   
51  
52  $.003$ ,  $\eta^2 = .025$ ,  $\text{BF}_{\text{incl}} = 47$  for just the interaction] indicating strong support for an effect of  
53  
54 onset complexity on the Stroop congruency effect.  
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3 Post-hoc tests revealed that this interaction was due to a larger significant congruency  
4 effect (119ms) for complex [ $t(68) = 9.922$ ,  $p(\text{Holm}) < 0.001$ ,  $d = .864$ ,  $\text{BF}_{10} = 3.559 \times 10^{11}$ ],  
5  
6 than for simple onsets (72ms) [ $t(68) = 5.984$ ,  $p(\text{Holm}) < .001$ ,  $\text{BF}_{10} = 268861$ ]. Comparing  
7  
8 word types across onset complexity conditions revealed that onset complexity mainly takes  
9  
10 its effect on Congruent items [ $t(68) = 3.371$ ,  $p = .002$ ,  $d = .244$ ,  $\text{BF}_{10} = 18.309$ ] as the effect  
11  
12 on Incongruent items remained nonsignificant [ $t(68) = 1.385$ ,  $p = .171$ , with the Bayes Factor  
13  
14 providing moderate evidence for the null,  $\text{BF}_{01} = 3.042$ ]. Therefore, this latter effect of onset  
15  
16 complexity on the Stroop Congruency Effect is likely to result from changes on Stroop  
17  
18 facilitation instead of interference. Two supplementary ANOVAs and their Bayesian  
19  
20 equivalents were then run to directly to address this idea directly.  
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### 28 *Effect of onset complexity on Stroop interference*

29  
30 2 (Word Type: Incongruent vs. Neutral) x 2 (Onsets: Complex vs. Simple) repeated-  
31  
32 measures analyses using the neutral trials that matched to the colour word for onset type  
33  
34 (CNC and SNS for complex and simple onset Stroop effects, respectively) further revealed  
35  
36 the main effect of Word Type [ $F(1, 68) = 92.828$ ,  $p < .001$ ,  $\eta^2 = .429$ ,  $\text{BF}_{10} = 3.24 \times 10^{11}$ ].  
37  
38 However, both main effect of Onset [ $F(1, 68) = 1.741$ ,  $p = .191$ ,  $\text{BF}_{10} = 0.318$ ] and the Word  
39  
40 Type x Onset interaction remained nonsignificant [ $F(1, 68) = 1.248$ ,  $p = .268$ ; with  $\text{BF}_{\text{incl}} =$   
41  
42 0.302 for just the interaction] further suggesting that the aforementioned onset complexity  
43  
44 effect on the magnitude of Stroop Congruency is unlikely to result from changes on Stroop  
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46 interference and results from changes in facilitation instead.  
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### 54 *Effect of onset complexity on Stroop facilitation*

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56 This latter idea is directly suggested by the results of a 2 (Word Type: Congruent vs.  
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58 Neutral) x 2 (Onsets: Complex vs. Simple) repeated-measures ANOVAs revealing an  
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3 interaction between Word Type and Onsets [ $F(1, 68) = 8.581, p = .005, \eta^2 = .045$ , with  $BF_{incl}$   
4 = 57 indicating strong support for the interaction alone) in addition to main effect of both  
5  
6 Word Type [ $F(1, 68) = 4.407, p < .040, \eta^2 = .016, BF_{10} = 106$ ] and of Onset [ $F(1, 68) =$   
7  
8 8.819,  $p = .004, \eta^2 = .038, BF_{10} = 3.588$ , albeit with an anecdotal Bayes Factor favouring the  
9  
10 null,  $BF_{10} = 0.608$ ]. Further post-hoc tests additionally revealed that the interaction was due  
11  
12 to significant *positive* facilitation of 28ms for complex onsets [ $t(68) = 3.594, p(\text{Holm}) =$   
13  
14 0.002,  $d = .224, BF_{10} = 23$ ], and non-significant *negative* facilitation of -7ms for simple  
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16 onsets [ $t(68) = 0.896, p(\text{Holm}) > .9, BF_{10} = 0.204$ ].  
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22 --- Insert Table 3 about here ---  
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## 28 Discussion

29 The aim of the present study was to explore how onset complexity affects Stroop task  
30 performance. The results from the present experiment convincingly show an onset  
31 complexity effect on Stroop task performance such that complex onsets increase the  
32 magnitude of positive facilitation and the Stroop congruency effect. Both effects were driven  
33 by the fact that congruent words with complex onsets were responded to more quickly than  
34 congruent words with simple onsets. This result, along with the null effects of onset  
35 complexity on both incongruent and neutral words trials suggest the onset complexity effect  
36 was driven by the activation of the phonological / phonetic representation of the correct  
37 response, facilitating the classification of the colour (this is discussed further in the General  
38 Discussion). This facilitating effect of complex onsets is consistent with the notion that  
39 subvocal production of the colour name occurs even with a manual response (Parris et al.,  
40 2019; but see Kinoshita et al. 2020), and is also consistent with a complexity advantage in  
41 word reading (Kawamoto & Kello, 1999; Rastle & Davis, 2002).  
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3 The finding of robust positive facilitation in a mostly neutral word context is  
4 somewhat unusual. Complex onsets appear to have created positive facilitation where  
5 otherwise there would not have been. As Parris et al. (2023) have pointed out, when  
6 presented in a mostly neutral word trial context, positive facilitation is not observed  
7 (Goldfarb & Henik, 2007, Experiment 2; see also Shichel & Tzelgov, 2018); rather there is  
8 no positive nor negative facilitation. This is in fact what we observe in the simple onset  
9 condition in the present experiment. Thus, the finding of robust positive facilitation in the  
10 complex onset condition is notable and indicates an extra level of information contributing to  
11 performance.  
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24 Given the effect on congruent trials, it is somewhat surprising that the subvocal  
25 production of the incongruent colour name – corresponding to the incorrect response – did  
26 not also modify performance. Whilst a larger magnitude of interference was observed for the  
27 complex onset incongruent stimuli (i.e., 97ms as compared to 79ms), the data are best  
28 interpreted as showing no effect of onset complexity on incongruent trial RTs. It is also the  
29 case that there was no onset complexity effect for neutral stimuli. An effect of onset  
30 complexity on neutral and incongruent trials would be expected if the onset complexity effect  
31 in the Stroop task were driven by just the phonological processing of the irrelevant word.  
32 However, it is also notable that the size of the effect in the present study (~35ms) was much  
33 larger than that reported in studies of intentional word reading (~7ms). Taken together, the  
34 present results indicate that the onset complexity effect in the Stroop task is different from  
35 that seen in studies of intentional word reading. The lack of an effect of onset complexity on  
36 incongruent and neutral trials suggests that the onset complexity effect in the Stroop task  
37 requires that the phonological codes of the word and colour name match; only then is the  
38 complexity advantage observed. Indeed, the lack of an onset effect on neutral and  
39 incongruent trials represents a limitation of the use of onset complexity as a manipulation; If  
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3 the onset effect were apparent in the neutral and incongruent trials in the mostly xxxx trial  
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5 context, it would have least enabled us to argue that the disappearance of negative facilitation  
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7 is indicative of negative facilitation reflecting a different form of conflict to informational  
8  
9 conflict.  
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11  
12 In intentional reading, the onset complexity effect results from the faster compilation  
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14 of the phonetic code of the written word but the results from the present study suggest that in  
15  
16 the Stroop task the complexity advantage is related to the benefit the phonetic code of the  
17  
18 written word has on the subvocal production of the acoustic code of the colour name. Thus,  
19  
20 despite the difference in the ease with which neutral words with complex vs. simple onsets  
21  
22 are read aloud (Rastle & Davis, 2002), there appear to be no implications for colour  
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24 responding. It is not therefore the pronounceability of the irrelevant word alone that matters;  
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26 it is the relationship between the pronounceability of the irrelevant word and the correct  
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28 colour name. Onsets that do not have congruent phonetic codes, whether they refer to  
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30 incongruent colours or neutral words, do not influence colour categorisation performance.  
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## 40 **Experiment 2**

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42 The aim of this experiment was to investigate whether onset complexity affects negative  
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44 facilitation. To do this, the mostly neutral word context employed in Experiment 1 was  
45  
46 replaced by a mostly non-pronounceable, repeated-letter stimuli context; a context shown to  
47  
48 repeatedly produce negative facilitation (Entel & Tzelgov, 2018; 2020; Goldfarb & Henik,  
49  
50 2007; Kalanthroff et al., 2013). Given the effect of onset complexity reported above, it was  
51  
52 predicted that colour-identification times for colour-congruent words with complex onsets  
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54 would reduce or eliminate negative facilitation relative to irrelevant words with simple  
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56 onsets. Such a finding would be consistent with the alternative account of negative  
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3 facilitation based on differences in pronounceability. In contrast to the alternative account,  
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5 the task conflict account of negative facilitation indicates that the longer RTs to congruent  
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7 trials result from competition between task sets. Since words with both complex and simple  
8  
9 onsets equally fulfil the criteria of being words, they should both equally activate the task set  
10  
11 for word reading and thus produce similar amounts of negative facilitation.  
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15 As with Experiment 1, in the present experiment we contrasted the effect of irrelevant  
16  
17 colour words with simple onsets (i.e., red and purple) and irrelevant colour words with  
18  
19 complex onsets (i.e., blue and green) on Stroop task performance. To ensure orthogonal  
20  
21 comparisons for facilitation and interference effects, half the repeated-letter stimuli were  
22  
23 employed as the neutral baseline for the complex onset colour word stimuli and half were  
24  
25 employed as the baseline for the simple onset colour word stimuli (and the repeated-letter  
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27 stimuli sets were matched for length with their word counterparts).  
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## 33 **Method**

### 34 *Design*

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37 3 (Word Type: Incongruent vs. Congruent vs. Repeated-letter neutral) x 2 (Onsets: Complex  
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39 vs. Simple) repeated-measures design with reaction times as the dependent variable.  
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### 42 *Participants*

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44 90 new participants were recruited through the online testing platform, Testable  
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46 (testable.org). The inclusion criteria were the same as those in Experiment 1. All participants  
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48 were paid \$4.50. Of the 90 participants, 9 were removed for reporting a language other than  
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50 English as their first language, 3 were removed for having >70% errors in any one of the  
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52 experimental conditions, and 3 were removed because they had previously completed a  
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54 similar study. Of the remaining 74 participants, 45 were male. The ages ranged from 21-57  
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56 with an average age of 32.7 (SD = 9.4).  
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### *Stimuli and Procedure*

The stimuli and procedure were identical to Experiment 1 with the exception of the repeated-letter baseline that replaced the neutral-word baseline. The repeated-letter stimuli used in this experiment were matched in length to the colour words (e.g., xxx for red, xxxxx for green).

The stimuli were presented in Testable's default font size and style.

### **Results**

Only data from correct trials were used in this analysis (7.8% of data were removed as errors). None of the error analyses produced anything other than a main effect of Word Type and thus are not reported below (see Table 4 for error percentages). Any RTs greater than 2SDs either side of the overall mean were removed from analysis resulting in the removal of 5.3% of correct trials.

#### ***Effect of onset complexity on Negative Facilitation***

To assess the effect of onset complexity on negative facilitation, the data were entered into a 2 (Word Type: Congruent vs. Repeated-letter) x 2 (Onset: Complex vs. Simple) repeated-measures ANOVA and its Bayesian equivalent. Analysis revealed no main effect of Onset [ $F(1, 73) = 0.174, p = .678$  with  $BF_{01} = 6.579$  supporting the null] and a non-significant Onset x Word Type interaction [ $F(1, 73) = 0.003, p = .953$  with  $BF_{01} = 40.667$ ] showing strong evidence against the interaction. However, there was also not strong evidence for the presence of negative facilitation. Indeed, the main effect of Word Type was significant with standard inferential ANOVA [ $F(1, 73) = 5.445, p = .022, \eta^2 = .021$ ], but the Bayes Factor was anecdotal,  $BF_{10} = 1.082$  (see Figure 2; see Table 4 for RTs, errors and Stroop effects).

### *Effect of onset complexity on the Stroop Congruency Effect*

Whilst the main aim of the present experiment was to explore the effect of onset complexity on negative facilitation, here we analyse the effect of onset complexity on the Stroop congruency effect to permit a more direct comparison with Experiment 1. The data were entered into a 2 (Onset: Complex vs. Simple) x 2 (Word Type: Congruent vs. Incongruent) repeated-measures ANOVA. This analysis revealed no main effect of Onset where  $F(1, 73) = 0.726, p = .397, BF_{01} = 5.470$ . The main effect of Word Type was significant where  $F(1, 73) = 161.249, p < .001, \eta^2 = .487, BF_{10} = 1.416 \times 10^{17}$ . The main effect was the result of an overall congruency effect of 118.1ms where  $t(73) = 12.698, p(\text{Holm}) < 0.001, BF_{10} = 1.416 \times 10^{17}$ . The Onset and Word Type interaction was not significant,  $F(1, 73) = 1.076, p = .303$ , and this was supported by the Bayes Factor for the contribution of the interaction alone ( $BF_{\text{excl}} = 4.725$ ).

In sum, whilst we observed at least some evidence for negative facilitation, this was not modified by onset complexity. Furthermore, there evidence against an effect of onset complexity on the Stroop congruency effect.

--- Insert Table 4 about here ---

### **Discussion**

Despite employing an experimental context that has been shown to produce robust negative facilitation effects in previous studies (i.e., 75% repeated-letter stimuli; e.g., Entel & Tzelgov, 2018; Goldfarb & Henik, 2007; Kalanthroff et al., 2013), we were only able to provide weak evidence for negative facilitation in the present experiment. Parris et al. (2023) noted that for large and robust negative facilitation to be produced via the mostly non-lexical trial context, two other factors need to be present: 1) spare working memory capacity; 2) anticipation of informational conflict in the form of incongruent trials (see Entel & Tzelgov, 2018; 2020). In

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3 the present experiment there was no working memory load imposed on the participants and  
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5 incongruent trials were included. It is therefore somewhat surprising that the overall main  
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7 effect of negative facilitation was so small.  
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10 In terms of the main aim of the current experiment, the Bayes Factor provided  
11  
12 evidence for no effect of onset complexity on negative facilitation and, furthermore, there  
13  
14 was no effect of onset complexity evident at all in the data – congruent trials were unaffected  
15  
16 by onset type. Given that the only difference between the present experiment and  
17  
18 Experiment 1 was the presence of the mostly repeated-letter (Experiment 2) context it is  
19  
20 likely that the mostly repeated-letter context was responsible for the lack of an onset  
21  
22 complexity effect in the present experiment. However, before interpreting the result from the  
23  
24 present experiment we felt it important to first replicate the onset complexity effect observed  
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26 in Experiment 1.  
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### 33 **Experiment 3**

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35 Given the lack of an onset complexity effect in Experiment 2 the aim of the present  
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37 experiment was to replicate the onset complexity effect observed in Experiment 1. Therefore,  
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39 the following experiment was identical to Experiment 1 except that only one set of neutral  
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41 words was used since there was no difference between the two sets in Experiment 1 ( $p > .05$ )<sup>1</sup>.  
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58 <sup>1</sup> We had also included a repeated-letter condition (i.e., 48 xxxx trials) in the present experiment to enable  
59 calculation of facilitation effects relative to this baseline, but an error in programming meant that the data for  
60 this condition was unusable.



## Method

### *Design*

4 (Word Type: Incongruent vs. Congruent vs. Neutral Complex vs. Neutral Simple) x 2 (Onsets: Complex vs. Simple) repeated-measures design with reaction times as the dependent variable.

### *Participants*

In total 124 participants were recruited through the online testing platform, Testable (testable.org). Participants had to fulfil the same criteria as the previous two experiments. None of them participated in Experiments 1 and 2. All participants were paid \$5. Of the 124 participants, 8 were removed for reporting a language other than English as their first language, and 6 were removed for having >70% errors in any one of the experimental conditions. Of the remaining 110 participants, 52 were male. The ages ranged from 19-64 with an average age of 32.9 years (standard deviation = 10.1).

### *Stimuli and Procedure*

Identical to Experiment 1 with the exception that: 1) only one set (Set 1) of neutral words were used given no differences were observed between the two sets in Experiment 1 ( $p > .8$ ); 2) An additional 48 repeated-letter trials were included to enable the calculation of facilitation effects relative to this new baseline. However, as noted in footnote 1, a programming error meant that the data from this condition were unusable and are therefore not reported below.

## Results

Only data from correct trials are reported below since there were no effects in the error data other than main effects of Word Type (8.7% of data were removed as errors – see Table 5 for error percentages as a function of condition). Any RTs greater than 2SDs either side of the

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3 overall mean were removed from analysis resulting in the removal of 5.1% of the correct  
4  
5 trials.  
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8 The data were entered into a 4 (Word Type: Incongruent vs. Complex Neutral vs.  
9  
10 Simple Neutral vs. Congruent) x 2 (Onsets: Complex vs. Simple) repeated-measures  
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12 ANOVA and its Bayesian equivalent (see Figure 3; see Table 5 for means, percentage errors  
13  
14 and Stroop effects). These analyses revealed a main effect of Word Type [ $F(1.924, 209.7)$ ,  
15  
16 Greenhouse-Geisser = 147.917,  $p < .001$ ,  $\eta^2 = .398$ ,  $BF_{10} = 6.250 \cdot 10^{56}$ ], and a main effect of  
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18 Onset [ $F(1, 109) = 4.776$ ,  $p = .031$ , although this was not supported by the Bayes Factor  
19  
20 which favoured the null,  $BF_{10} = 0.314$ ]. The interaction between Word Type and Onsets was  
21  
22 also significant [ $F(2.103, 229.246)$ , Greenhouse-Geisser = 5.087,  $p = .006$ ,  $\eta^2 = .011$ ] with  
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24  $BF_{incl} = 24.137$  for just the interaction (i.e., without the main effects also included in the  
25  
26 model).  
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31 The interaction was further decomposed into two one-way repeated-measures  
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33 ANOVAs and their Bayesian equivalents investigating Stroop effects in the Complex Onset  
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35 and Simple Onset conditions independently. A significant ANOVA for the Complex Onset  
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37 stimuli [ $F(3, 327) = 108.593$ ,  $p < .001$ ,  $\eta^2 = .499$ ,  $BF_{10} = 1.722 \cdot 10^{45}$ ] was underpinned by a  
38  
39 significant overall Stroop congruency effect (i.e., mean difference between Congruent and  
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41 Incongruent trials) of 116ms [ $t(109) = 17.115$ ;  $p(\text{Holm}) < .001$ ,  $d = 0.968$ ,  $BF_{10} =$   
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43  $8.796 \cdot 10^{21}$ ]. The congruency effect resulted from significant positive facilitation of 32ms  
44  
45 [ $t(109) = 4.668$ ,  $p(\text{Holm}) < .001$ ,  $d = .264$ ,  $BF_{10} = 5088$ ] and a significant Stroop interference  
46  
47 effect (84ms) [ $t(109) = 12.447$ ,  $p(\text{Holm}) < .001$ ,  $d = .704$ ,  $BF_{10} = 1.939 \cdot 10^{18}$ ] when CNC  
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49 stimuli were used as a color-neutral comparison baseline. When SNC stimuli were used, the  
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51 congruency effect resulted from significant positive facilitation of 30ms, [ $t(109) = 4.353$ ,  
52  
53  $p(\text{Holm}) < .001$ ,  $d = .246$ ,  $BF_{10} = 1219$ ]; and a significant Stroop interference effect of 87ms,  
54  
55 [ $t(109) = 12.762$ ,  $p(\text{Holm}) < .001$ ,  $d = .721$ ,  $BF_{10} = 5.728 \cdot 10^{17}$ ]. And consistent with  
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3 Experiment 1, reaction times to Neutral stimuli with Complex vs. Simple onsets did not differ  
4 significantly [2ms;  $t(109) = 0.315$ ,  $p(\text{Holm}) = .753$ ] where the Bayes Factor supported the  
5  
6 null,  $\text{BF}_{10} = 0.124$ .  
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10 A significant ANOVA for the Simple Onset stimuli [ $F(3, 327) = 62.590$ ,  $p < .001$ ,  $\eta^2 =$   
11  
12  $.365$ ,  $\text{BF}_{10} = 4.933 \times 10^{28}$ ] was underpinned by a significant Stroop Congruency effect of 84ms  
13  
14 [ $t(109) = 11.294$ ,  $p(\text{Holm}) < .001$ ,  $d = 0.688$ ,  $\text{BF}_{10} = 9.508 \times 10^9$ ]. This latter effect resulted  
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16 from non-significant negative facilitation [i.e., -2ms;  $t(109) = 0.239$ ,  $p(\text{Holm}) > .9$ ,  $\text{BF}_{10} =$   
17  
18  $0.109$ ]; and a significant Stroop interference effect of 82ms [ $t(109) = 11.054$ ,  $p(\text{Holm}) < .001$ ,  
19  
20  $d = .674$ ,  $\text{BF}_{10} = 1.813 \times 10^{15}$ ] when CNS stimuli were used as a color-neutral comparison  
21  
22 baseline. When SNC stimuli were used to this end, the aforementioned congruency effect  
23  
24 resulted from non-significant negative facilitation [i.e., -1ms;  $t(109) = 0.82$ ,  $p(\text{Holm}) > .9$ ,  
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26  $\text{BF}_{10} = 0.106$ ]; and a significant Stroop interference effect of 83ms [ $t(109) = 11.212$ ,  $p(\text{Holm})$   
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28  $< .001$ ,  $d = .683$ ,  $\text{BF}_{10} = 1.532 \times 10^{16}$ ]. Again, reaction times to Neutral stimuli with Complex  
29  
30 vs. Simple onsets did not differ significantly [1ms;  $t(109) = 0.157$ ,  $p(\text{Holm}) > .9$ ] where the  
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32 Bayes Factor favoured the null,  $\text{BF}_{10} = 0.112$ .  
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### 40 *Effect of onset complexity on the Stroop Congruency Effect*

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42 To assess the effect onset complexity on the Stroop congruency effect further, the data  
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44 were entered into a 2 (Onsets: Complex vs. Simple) x 2 (Word Type: Congruent vs.  
45  
46 Incongruent) repeated-measures ANOVA and its Bayesian equivalent. These analyses  
47  
48 revealed a significant main effect of Word Type [ $F(1, 109) = 201.653$ ,  $p < .001$ ,  $\eta^2 = .426$ ,  
49  
50  $\text{BF}_{10} = 1.936 \times 10^{23}$ ] and a main effect of Onset [ $F(1, 109) = 5.587$ ,  $p = .020$ , but where the  
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52 Bayes Factor was anecdotal  $\text{BF}_{10} = 0.732$ ]. The interaction was also significant [ $F(1, 109) =$   
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54  $6.382$ ,  $p = .013$ ,  $\eta^2 = .011$ ,  $\text{BF}_{\text{incl}} = 7.077$  for just the interaction] indicating strong support for  
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56 an effect of onset complexity on the Stroop congruency effect.  
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3 Post-hoc tests revealed that this interaction was due to a larger significant congruency  
4 effect (116ms) for complex [ $t(109) = 12.220, p(\text{Holm}) < 0.001, d = .910, \text{BF}_{10} = 8.796 \times 10^{21}$ ],  
5 than for simple onsets (84ms) [ $t(109) = 8.829, p(\text{Holm}) < .001, \text{BF}_{10} = 9.508 \times 10^9$ ]. Comparing  
6 word types across onset complexity conditions revealed that onset complexity takes its effect  
7 on Congruent items [ $t(109) = 3.370, p = .001, d = .321, \text{BF}_{10} = 20.646$ ] and not on  
8 Incongruent items remained nonsignificant [ $t(109) = 0.410, p = .683$ , with the Bayes Factor  
9 providing moderate evidence for the null,  $\text{BF}_{10} = 0.115$ ]. Therefore, as shown in Experiment  
10 1, the effect of onset complexity on the Stroop Congruency Effect results from changes to  
11 congruent trials.  
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### 26 ***Effect of onset complexity on Stroop interference***

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28 A 2 (Word Type: Incongruent vs. Neutral) x 2 (Onsets: Complex vs. Simple)  
29 repeated-measures analyses using the neutral trials that matched to the colour word for onset  
30 type (CNC and SNS for complex and simple onset Stroop effects, respectively) revealed no  
31 Word Type x Onset interaction [ $F(1, 109) = 0.018, p = .893$ ; with  $\text{BF}_{\text{incl}} = 0.123$  for just the  
32 interaction].  
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### 43 ***Effect of onset complexity on Stroop facilitation***

44 Consistent with Experiment 1 a 2 (Word Type: Congruent vs. Neutral) x 2 (Onsets:  
45 Complex vs. Simple) repeated-measures ANOVAs revealed an interaction between Word  
46 Type and Onsets [ $F(1, 109) = 9.410, p = .003, \eta^2 = .033$ , with  $\text{BF}_{\text{incl}} = 259$  indicating strong  
47 support for the interaction alone). Further post-hoc tests additionally revealed that the  
48 interaction was due to significant *positive* facilitation of 32ms for complex onsets [ $t(109) =$   
49  $4.840, p(\text{Holm}) < 0.001, d = .257, \text{BF}_{10} = 5089$ ], and non-significant *positive* facilitation of  
50 1ms for simple onsets [ $t(109) = 0.093, p(\text{Holm}) > .9, \text{BF}_{10} = 0.106$ ].  
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## 8 **Discussion**

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10 Given the lack of an onset effect in Experiment 2, the aim of the present experiment was to  
11 replicate the onset effect observed in Experiment 1. The results from the present experiment  
12 provide a clear replication of Experiment 1 showing faster colour responses to congruent  
13 words with complex onsets than to congruent words with simple onsets. This resulted in an  
14 onset complexity effect on the Stroop congruency and positive facilitation effects, but not on  
15 interference effects. Moreover, the results from the present experiment confirm that colour  
16 categorisation responses to neutral words with complex onsets do not differ from colour  
17 categorisation responses to neutral words with simple onsets. The results from both  
18 Experiment 1 and Experiment 3 therefore indicate that colour congruency is required to  
19 observe an effect of onset complexity on Stroop task performance.  
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## 35 **General Discussion**

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37 The aim of the present set of experiments was twofold: 1) To investigate whether onset  
38 complexity modifies the magnitude of the common Stroop effects of Stroop interference,  
39 Stroop (positive) facilitation and the Stroop congruency effect (Experiments 1 and 3); 2)  
40 Investigate whether onset complexity modifies the magnitude of negative facilitation  
41 (Experiment 2). Regarding the first aim, the results from both Experiments 1 and 3 provide  
42 strong evidence for an effect of onset complexity on Stroop effects. Specifically, both  
43 positive facilitation and the Stroop congruency effect (Experiments 1 and 3) were increased  
44 when irrelevant colour words had complex onsets (e.g., *blue* and *green* vs. *red* and *purple*)  
45 due to the effect of onset complexity on congruent trials. There was no evidence for an effect  
46 of onset complexity on Stroop interference nor when the irrelevant word was a neutral, non-  
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3 colour related word indicating that the effect of onset complexity was at the level of encoding  
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5 the phonology of the correct response. Indeed, as noted above, the lack of an effect on  
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7 incongruent and neutral trials represents somewhat of a limitation for the use of onset  
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9 complexity for present purposes: if the onset effect was apparent in the neutral and  
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11 incongruent trials in the mostly xxxx trial context, it would have least enabled us to argue that  
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13 the disappearance of negative facilitation is indicative of the phenomenon reflecting a  
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15 different form of conflict to informational conflict.  
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19 The finding of an effect of onset complexity in the Stroop task is novel and is  
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21 consistent with the complexity advantage observed in word reading studies (Kawamoto &  
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23 Kello, 1999; Rastle & Davis, 2002). The results are consistent with the notion that complex  
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25 onsets are beneficial to word processing (O'Seaghdha et al., 1992; Taraban & McClelland,  
26  
27 1987). Furthermore, this result was obtained in a task in which the words are not read aloud,  
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29 and moreover, responses were manual, supporting the notion that phonological processing of  
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31 the irrelevant word happens with manual responses (Parris et al., 2019; cf. Kinoshita et al.,  
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33 2018; see below for a discussion of this issue). However, it is clear that the onset complexity  
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35 effect reported here is not the same as that reported in studies of intentional reading. The  
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37 magnitude of the effect was much larger and the effect was limited to when the complex  
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39 onset of the irrelevant word matched the complex onset of the colour name; colour name  
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41 congruency is the *sine qua non* of the onset complexity effect in Stroop task performance. In  
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43 the Stroop task it is the match between the phonological code of the irrelevant word and the  
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45 phonetic code of the colour name that results in the onset complexity effect.  
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51 In terms of the second aim of the present study, there was no effect of onset  
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53 complexity on negative facilitation. Indeed, there was no evidence of an onset effect in  
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55 Experiment 2 indicating that the mostly repeated-letter context prevented the onset effect  
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57 observed in Experiments 1 and 3. Onset complexity was manipulated because we thought that  
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3 any factor that makes phonetic encoding more difficult (simple onset stimuli in the present  
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5 study) would delay colour naming, enhancing negative facilitation. This is in contrast to the  
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7 task conflict account of negative facilitation which states that congruent trials RTs are longer  
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9 because they involve task conflict whilst non-lexical trials do not. And whilst simple onset  
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11 stimuli did delay colour naming of congruent items relative to complex onset stimuli in  
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13 Experiments 1 and 3, it did not modify negative facilitation in Experiment 2. It is notable  
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15 however that we did not observe large negative facilitation effects despite including  
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17 experimental conditions that produce it such as a mostly non-lexical trial context, spare  
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19 working memory capacity and exposure to incongruent trials (Parris et al., 2023).  
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22 Nevertheless, the small main effect of negative facilitation would not in itself preclude  
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24 variation in the two onset conditions. However, the evidence for a null interaction effect was  
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26 clear and therefore the best interpretation of the data is in line with the task conflict account  
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28 of negative facilitation: Given that both complex and simple onset words equally fulfil the  
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30 criteria of being words meaning the task conflict account predicts they would both produce  
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32 similar amounts of negative facilitation relative to a non-lexical baseline.  
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38 Since the onset complexity effect observed in Experiment 1 and 3 is one based on  
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40 positive facilitation, the absence of an onset effect in Experiment 2 could be explained by the  
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42 general effect of mostly neutral word or mostly non-lexical trial contexts on positive  
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44 facilitation (Parris et al., 2023; see below for a fuller discussion of this issue). Parris et al.  
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46 (2023) noted that positive facilitation seems to be prevented when the experimental context is  
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48 either mostly neutral words or mostly non-lexical stimuli. This would mean that an effect that  
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50 finds its expression only in positive facilitation would be unlikely to be observed in such  
51  
52 contexts. This means that the onset effect is not therefore an ideal test of the alternative  
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54 account. If the onset complexity effect were also observable in other measures of  
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56 informational conflict such as the Stroop interference effect, it could have potentially  
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3 produced an effect of onset complexity in Experiment 2 in all conditions except the congruent  
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5 condition thereby indicating that negative facilitation is qualitatively different from  
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7 informational conflict (the alternative account argues that negative facilitation is just another  
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9 form of informational (phonological) conflict). Without this more pervasive effect on indices  
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11 of Stroop task performance, it is unclear whether a strong test of the alternative account has  
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13 been provided.  
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### 19 **The effect of a mostly non-lexical trial context**

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22 The finding of a lack of an onset complexity effect in Experiment 2 stands in stark contrast to  
23  
24 the findings of Experiments 1 and 3. The only difference between the experiments is the  
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26 mostly repeated-letter context in Experiment 2 (which replaced the mostly neutral word  
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28 context in Experiment 1). It therefore seems clear that the mostly repeated-letter context is  
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30 responsible for the lack of an onset effect. What is unclear is why the mostly repeated-letter  
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32 context would have this effect. Indeed, Parris et al., (2023) pointed out that the effect of the  
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34 mostly repeated-letter context needs further explanation given two opposing accounts from  
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36 task conflict theorists: according to Kalanthroff et al. (2018)'s model the mostly non-lexical  
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38 context induces a low task conflict control state because task conflict is not encountered often  
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40 enough, reducing proactive control (see also Spinelli and Lupker (2021, 2022) who argue that  
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42 the mostly non-lexical trial context reduces proactive control – although not in a way that is  
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44 related to task conflict per se). Given that proactive control is low, task conflict is high, which  
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46 leads to an inhibition mechanism modifying the response threshold to all lexical stimuli. This  
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48 raising of the response threshold would not happen for repeated letter string trials (e.g., xxxx)  
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50 because the task unit for word reading would not be activated for these trials. Since responses  
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52 to congruent trials would be slowed relative to non-lexical trials under these conditions,  
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54 negative facilitation would result. And since this raising of the response threshold would  
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3 occur equally for all lexical stimuli it would not differentiate words with simple and complex  
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5 onsets, which would therefore not differ in terms of negative facilitation – as supported by the  
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7 results from the present study.  
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11 In contrast to this account, Entel and Tzelgov (2020) reasoned that a larger number of  
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13 non-lexical trials means that participants are less likely to inadvertently read the congruent  
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15 word, thereby increasing RTs to congruent words, and revealing negative facilitation and thus  
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17 task conflict relative to an *xxxx* baseline. This account would also presumably predict  
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19 reduced phonological processing of congruent trials in this context. If phonological  
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21 processing of words is reduced, one would expect mitigation of phonological-based effects,  
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23 especially in a manual response Stroop task (Parris et al., 2019). A future experiment  
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25 investigating onset complexity with a vocal response Stroop task that promotes phonological  
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27 processing of irrelevant stimuli might provide an interestingly contrasting set of results.  
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33 In contrast to both of these accounts, the alternative account of negative facilitation,  
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35 tested in the present study, argued that the mostly repeated-letter, non-pronounceable trial  
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37 context reduces control over word processing and therefore predicts larger informational  
38  
39 conflict and facilitation effects. This position was motivated by the finding of Kinoshita et al.  
40  
41 (2018) who reported larger semantic conflict effects relative to a neutral word baseline in the  
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43 mostly repeated-letter trial context (see also Shichel & Tzeglov, 2018, for evidence of greater  
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45 semantic conflict in a mostly repeated-letter trial context). According to this position the  
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47 onset complexity effect should be larger in the mostly repeated-letter trial context of  
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49 Experiment 2 than in the mostly neutral word context of Experiment 1 because control over  
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51 phonological (as well as semantic) processing should be reduced and onset effects therefore,  
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53 larger, in the former. This position finds no support in the current set of results (although the  
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55 position might still hold true for semantic conflict effects). In sum, the present results are  
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3 consistent with the notion that the mostly repeated-letter trial context discourages  
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5 phonological processing of presented letter strings and perhaps reduces inadvertent reading of  
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7 congruent items. However, since there is evidence that proactive control is reduced in this  
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9 mostly non-lexical trial context (Spinelli & Lupker, 2021, 2022) it is possible that positive  
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11 facilitation results from proactive control and thus intentional and not inadvertent reading. If  
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13 this is the case, then the effect of the mostly non-lexical context is not via lessening (Entel &  
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15 Tzelgov, 2019) or increasing (Parris et al., 2023) word processing, but on the amount of  
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17 proactive control that operates during task performance (Kalanthroff et al., 2018; Spinelli &  
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19 Lupker, 2021, 2022).  
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### 25 **The lack of an effect on onset complexity on neutral trials**

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27 A further notable finding from the present study was the lack of an effect of onset complexity  
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29 on neutral word stimuli in Experiments 1 and 3. This finding has implications for another  
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31 account of performance in selective attention paradigms. Parris et al. (2023) acknowledged  
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33 the similarities between their alternative account of negative facilitation and the Response  
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35 Exclusion Hypothesis (Mahon et al., 2007) in the picture-word interference literature. Under  
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37 the Response Exclusion Hypothesis (REH) irrelevant words get obligatorily processed right  
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39 up to the point of a representation entering an articulatory buffer; no selection occurs before  
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41 this very late point in processing and selection does not involve selection by competition.  
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43 Under this account words have privileged access to the articulators. Thus, as with Roelofs  
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45 (2003) and Glaser and Glaser (1989) models which are based on architectural differences  
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47 between word reading/naming and colour naming, the REH is based on architectural  
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49 differences between word reading/naming and picture naming. Specifically, the REH  
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51 describes this privileged access as being based on the “quasi rule-like relationship between  
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53 orthography and phonology” (p. 524; Mahon et al., 2007) and as such leads to a “production-  
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55 ready” representation for the articulators to produce. The REH uniquely predicts that low  
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3 frequency words should interfere more than high frequency words, a finding - mirrored in the  
4 colour-word Stroop literature (e.g., Burt, 2002) - that theories based on connectionist  
5 architecture (e.g., Cohen et al., 1990), find difficult to explain. Under the REH, distractor  
6 frequency effects arise because the earlier the response to the distractor enters the articulatory  
7 buffer, the earlier it can be removed from the buffer. Since low frequency words would take  
8 longer to reach the buffer, it takes longer to remove them from the buffer and thus colour  
9 naming times would be slowed.

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19 The aim of the present work was to test and further develop the alternative account of  
20 negative facilitation presented in Parris et al. (2023). The alternative account, like the REH,  
21 assumes that the phonological representation of a pronounceable distractor delays the  
22 response to the target colour. As with the REH, this means that phonological representations  
23 whose phonetic codes are produced sooner can be excluded sooner. Hence high-frequency  
24 words can be excluded faster than low frequency words and thus colour naming high  
25 frequency distractors is faster (Burt, 1994; 1999; 2002). Given this, the REH and the  
26 alternative account would predict that neutral words with complex onsets would have a  
27 useable production-ready representation before neutral words with simple onsets. This means  
28 that neutral words with complex onsets should be colour-named faster than neutral words  
29 with simple onsets. We did not observe this effect in the present study which means that our  
30 results contrast with this aspect of the REH and the alternative account (assuming that the  
31 onset complexity effect observed here is the result of phonological encoding). Nevertheless,  
32 future research should aim to further investigate this effect perhaps in a study that uses many  
33 neutral words to avoid repetition of a small stimuli set.

### Onset segment effects in Manual Stroop tasks

The present results have implications for recent debates on the type of processing that happens with manual response Stroop tasks. It has been argued that the mode of response used to classify the colour of the printed word (e.g., responding manually via a keypress vs. responding vocally by saying the colour name aloud) determines the magnitude and type of facilitation and interference that results (Augustinova et al., 2019; Fennell & Ratcliff, 2019; Glaser & Glaser, 1989; Kinoshita et al., 2017; McClain, 1983; Redding & Gerjets, 1977; Sharma & McKenna, 1998; Turken & Swick, 1999; Zahedi et al., 2019; see also MacLeod, 1991, and Parris et al., 2021). Accounts of differences between these two response modes propose differential access to the systems (i.e., phonological, lexico-semantic, or response level processing) that are assumed to produce interference and facilitation (Glaser & Glaser, 1989; Kinoshita et al., 2017; Sharma & McKenna, 1998; Sugg & McDonald, 1994; Turken & Swick, 1999; Virzi & Egeth, 1985; see also Fennell & Ratcliff, 2019; Zahedi et al., 2019). Consistent with this, it has recently been argued that vocal and manual responding involve different tasks (naming vs. classification, respectively) and as such the type of evidence that is accumulated during Stroop task performance is different, leading to qualitatively different Stroop effects and, importantly for present purposes, that phonological encoding does not occur with manual responses (Kinoshita et al., 2017; Kinoshita & Mills, 2020).

Onset segment effects on Stroop task performance were originally reported with a vocal response Stroop task. Coltheart and colleagues (1999) developed a novel Stroop paradigm by creating stimuli that either shared the initial phoneme or end phoneme of a colour name. For example, if the colour to be named was red, the to-be-ignored word would be *rat* (sharing initial phoneme) or *pod* (sharing the end phoneme) or a word that shares no phoneme at all (e.g., *fit*). Words that share a phoneme with a colour name have been shown to produce a naming latency advantage when naming the colour not the printed word (Regan,

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3 1978). Coltheart and colleagues reasoned that if, as assumed by the Dual Route Cascaded  
4 (DRC) model (see Coltheart et al., 2001), there is a serial order component in processing of  
5 print-to-speech, there will be an advantage for colour names that share an *initial* phoneme  
6 with the to-be-ignored written word compared to items that share an *end* phoneme because the  
7 computation of phonology from print is left to. Consistent with their predictions, Coltheart  
8 and colleagues reported that phonemic overlap was significant at both positions. However,  
9 facilitation was greater for items with overlap in the initial phoneme position which they  
10 argued is incompatible with models that do not assume a serial grapheme-to-phoneme  
11 processing route in reading (see also Marmurek et al., 2006, and Mousikou et al., 2015)<sup>2</sup>. In  
12 contrast to the computation-of-phonology-from-orthography account of this *position-sensitive*  
13 *Stroop effect*, Kinoshita and colleagues (2017, 2020) have argued that it reflects phonological  
14 encoding (and hence that any left-to-right serial processing effects reflect phonological  
15 encoding and not phonological computation).

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33 Kinoshita et al.'s arguments that phonological encoding does not happen with manual  
34 responses and that the left-to-right serial processing effects observed in Coltheart et al. (1999)  
35 and subsequent studies reflect phonological encoding, predicts that left-to-right serial  
36 processing effects should not be observed with manual responses. However, Parris et al.  
37 (2019) replicated Coltheart et al. (1999) with both vocal and manual response versions of the  
38 Stroop task, indicating that vocal and manual responses do not differ qualitatively, but only  
39 quantitatively (the effect of onset overlap was larger in the vocal response). The results from  
40 the present experiments are also therefore notable since they also indicate that phonological  
41 encoding occurs with the manual response Stroop task. According to Kinoshita and  
42 colleagues' position on the type of processing that can happen with a manual response, the  
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<sup>2</sup> See Marmurek, Proctor and Javor (2006) for a replication of this effect and for findings showing the same effect with non-words and an (albeit weaker) effect of onset overlap on Stroop interference, and Mousikou et al. (2015) for a replication with both pronounceable and non-pronounceable non-words.

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3 onset complexity effect observed in the present study would be due to phonological  
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5 computation and not phonological encoding.  
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10 In conclusion, the results from the present study show for the first time that onset  
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12 complexity modifies Stroop task performance whereby congruent words (but not neutral or  
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14 incongruent words) with complex onsets result in faster response times relative to congruent  
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16 words with simple onsets, thereby increasing Stroop facilitation and congruency effects. This  
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18 is consistent with the complexity advantage in intentional reading. Furthermore, in contrast to  
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20 the alternative account of negative facilitation that proposes that negative facilitation results  
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22 from difference in the pronounceability of irrelevant letter strings, onset complexity did not  
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24 modify the magnitude of negative facilitation. However, two findings mean that we cannot  
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26 conclusively reject the alternative account: 1) the negative facilitation effect was surprisingly  
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28 small in our study reducing the likelihood of its modification; 2) the onset complexity effect  
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30 took its effect by modifying positive facilitation only, the very index of performance that  
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32 appears to be generally prevented by mostly neutral (repeated-letter or neutral words) trial  
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34 contexts. Without a concomitant effect on incongruent and neutral trials, it is not possible to  
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36 determine whether negative facilitation is qualitatively different from informational conflict  
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38 (the alternative account argues that negative facilitation is just another form of informational  
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40 (phonological) conflict.  
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47 The results from this study have implications for understanding the levels of  
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49 processing of the irrelevant word with a manual response and indicate the need for a future  
50  
51 study comparing onset complexity effects in manual and vocal response Stroop tasks.  
52  
53 Moreover, the results from this study are favourable to the task conflict account of negative  
54  
55 facilitation, a theoretical approach that has provided insights into the nature of selective  
56  
57 attention including the suggestion of a new potential form of impairment that might explain  
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3 symptoms of clinical disorders such as obsessive-compulsive disorder (OCD; Kalanthroff et  
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5 al., 2017).  
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3 *Figure Captions*  
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5 *Figure 1. Task conflict theorists argue that “whole task sets compete, over and above any*  
6 *competition between specific responses associated with a stimulus” (Monsell et al., 2001:*  
7 *139-140). At some, as yet unclear, point in processing, the task set for word reading is*  
8 *activated, creating competition between task sets. That is, independent of, and likely earlier*  
9 *than some of the specific the S-R associations (in red), the task sets (which can be thought of*  
10 *as collections of S-R associations) compete, creating task conflict (a unique marker of which*  
11 *is negative facilitation). In contrast, the alternative account being tested here argues that the*  
12 *S-R associations in red are enough to explain negative facilitation given the differences in the*  
13 *pronounceability of non-lexical (i.e., xxxx) and lexical (e.g., blue) trials, especially in a*  
14 *mostly repeated-letter (e.g., 75%) trial context.*  
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30 *Figure 2. Button press colour classification times in the Stroop task as a function of Word*  
31 *Type and Onset Type in Experiment 1.*  
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37 *Figure 3. Button press colour classification times in the Stroop task as a function of Word*  
38 *Type and Onset Type in Experiment 2.*  
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44 *Figure 4. Button press colour classification times in the Stroop task as a function of Word*  
45 *Type and Onset Type in Experiment 3.*  
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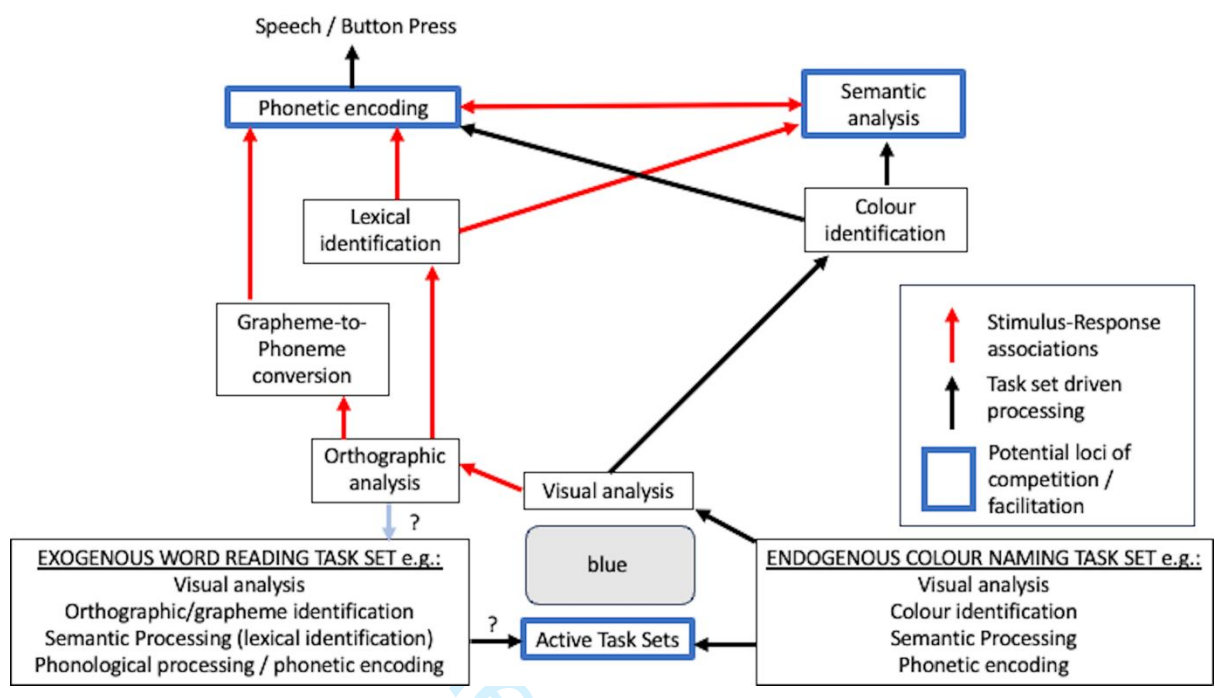
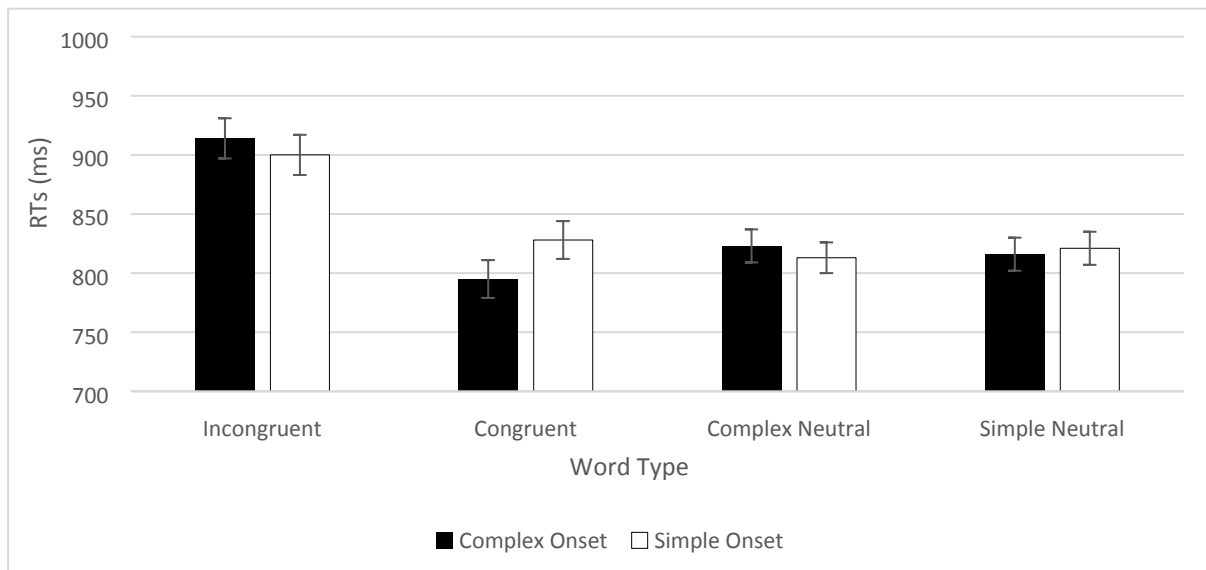


Figure 1. Task conflict theorists argue that “whole task sets compete, over and above any competition between specific responses associated with a stimulus” (Monsell et al., 2001: 139-140). At some, as yet unclear, point in processing, the task set for word reading is activated, creating competition between task sets. That is, independent of, and likely earlier than some of the specific the S-R associations (in red), the task sets (which can be thought of as collections of S-R associations) compete, creating task conflict (a unique marker of which is negative facilitation). In contrast, the alternative account being tested here argues that the S-R associations in red are enough to explain negative facilitation given the differences in the pronounceability of non-lexical (i.e., xxxx) and lexical (e.g., blue) trials, especially in a mostly repeated-letter (e.g., 75%) trial context.



*Figure 2. Button press colour classification times in the Stroop task as a function of Word Type and Onset Type in Experiment 1.*

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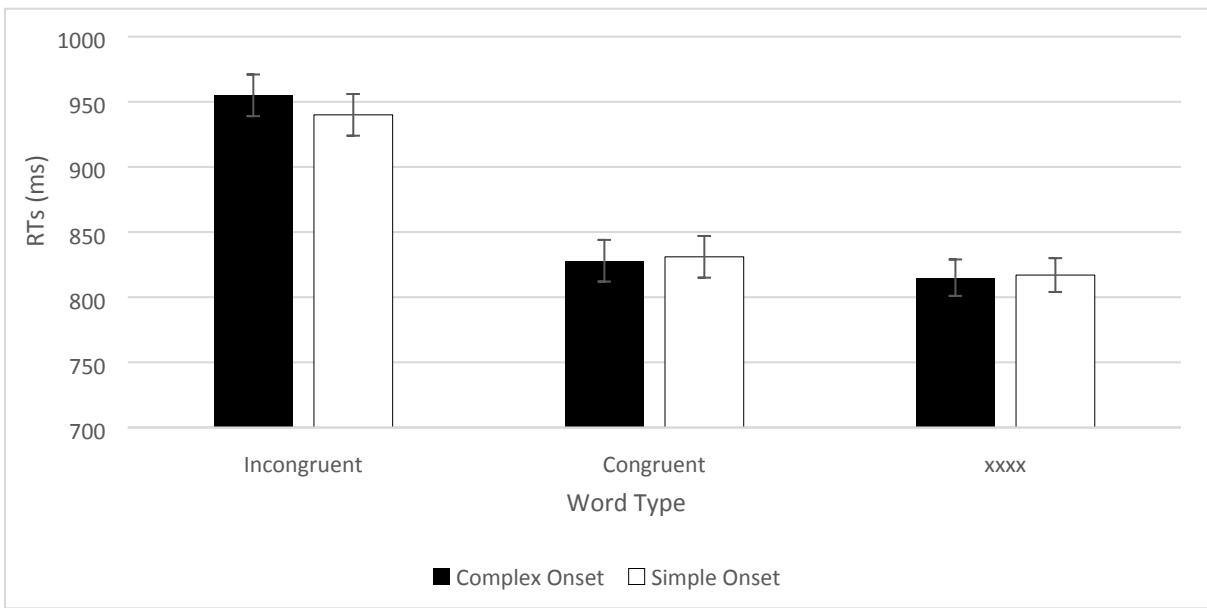


Figure 3. Button press colour classification times in the Stroop task as a function of Word Type and Onset Type in Experiment 2.

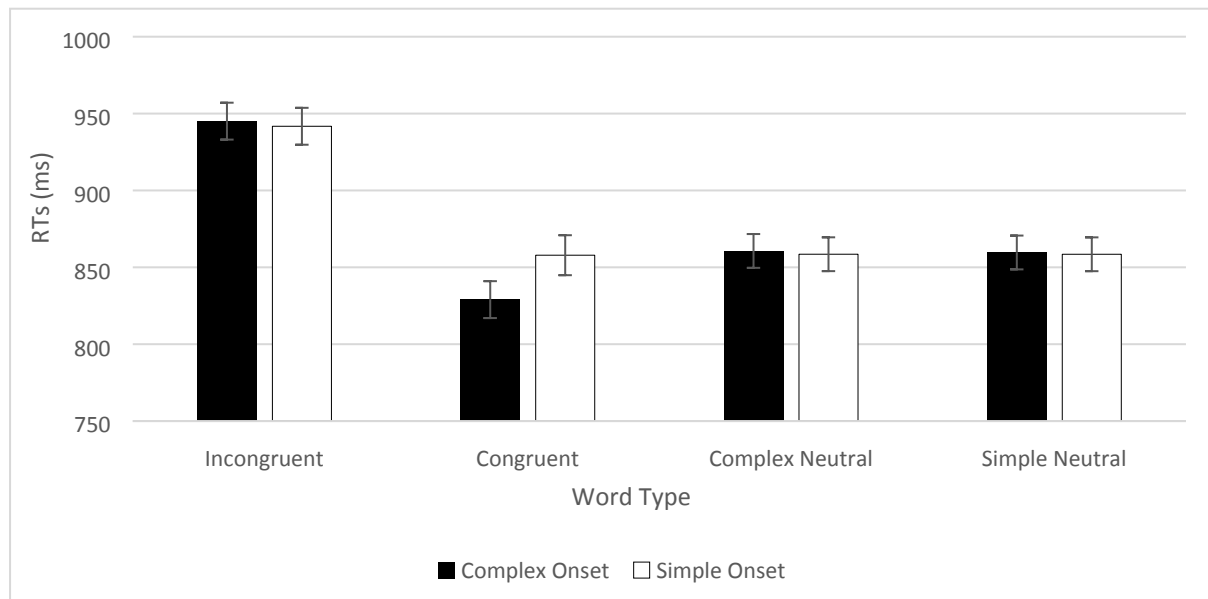


Figure 4. Button press colour classification times in the Stroop task as a function of Word Type and Onset Type in Experiment 3.

**Table 1***Stimulus characteristics in Experiment 1*

	Colour words		Neutral – Set 1		Neutral – Set 2	
	Complex	Simple	Complex	Simple	Complex	Simple
Number of letters	4.5	4.5	4.5	4.5	4.5	4.5
Number of phonemes	3.5	3.5	3.75	3.75	3.75	4.0
Number of syllables	1.00	1.5	1.25	1.25	1.25	1.25
Word Frequency <sup>a</sup>	87.43	80.19	50.18	75.26	69.47	91.37

Note. Stimulus characteristics for Congruent stimuli are identical to those for Incongruent stimuli. a: Subtitle word frequency (Brysbaert & New, 2009).

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**Table 2**

			<i>Colour names</i>			
			<i>Simple onset</i>		<i>Complex onset</i>	
			red	purple	green	blue
Experiments 1, 2 and 3	<i>Simple onset colour words</i>	red	12	4	4	4
		purple	4	12	4	4
	<i>Complex onset colour words</i>	green	4	4	12	4
		blue	4	4	4	12
Experiments 1 and 3	<i>Simple onset neutral words (Set 1)</i>	dog		12	12	12
		farmer	12		12	12
		taste	12	12		12
		cake	12	12	12	
	<i>Complex onset neutral words (Set 1)</i>	dry		12	12	12
		frozen	12		12	12
		train	12	12		12
	crew	12	12	12		
Experiment 1	<i>Simple onset neutral words (Set 2)</i>	far		12	12	12
		carbon	12		12	12
		force	12	12		12
		tape	12	12	12	
	<i>Complex onset neutral words (Set 2)</i>	fly		12	12	12
		clever	12		12	12
		floor	12	12		12
	tree	12	12	12		
Experiment 2	<i>Repeated-letter stimuli</i>	xxx		24	24	24
		xxxxxx	24		24	24
		xxxxx	24	24		24
		xxxx	24	24	24	

**Table 3***RTs, errors and Stroop effects as a function of onset complexity in Experiment 1.*

Onset	Word Type						Stroop effects			Complex vs. Simple Neutral		
	Incongruent		Congruent		Complex Neutral <sup>&amp;</sup>		Simple Neutral		Facilitation		Congruency Effect	Interference
	Mean (SE)	% Er	Mean (SE)	% Er	Mean (SE)	% Er	Mean (SE)	% Er				
Complex	914 (17)	9.8	795 (16)	6.2	823 (14)	7.1	816 (14)	6.6	28*	119*	91*	7 <sup>^</sup>
Simple	900 (17)	8.5	828 (16)	6.9	813 (13)	6.8	821 (14)	7.2	-7 <sup>^</sup>	72*	79*	-8
Difference	14 <sup>^</sup>		33*						35*	47*	12 <sup>^</sup>	

Note. \* $p < .01$ , <sup>^</sup>Evidence for null, <sup>&</sup>Note that half of the complex onset neutral trials were matched in length and frequency to the complex onset colour words and half were matched to the simple onset colour words. The same was true for the simple onset neutral stimuli. This meant that we could compare RTs for complex and simple onset neutral words that were matched on other psycholinguistic variables.



**Table 4**  
*RTs (ms), errors and Stroop effects as a function of onset complexity in Experiment 2.*

<i>Onset</i>	<i>Word Type</i>						<i>Stroop effects</i>		
	<i>Incongruent</i>		<i>Congruent</i>		<i>Neutral (xxxxx)</i>		<i>Facilitation</i>	<i>Congruency Effect</i>	<i>Interference</i>
	<i>Mean (SE)</i>	<i>% Er</i>	<i>Mean (SE)</i>	<i>% Er</i>	<i>Mean (SE)</i>	<i>% Er</i>			
<i>Complex</i>	955 (16)	10.8	828 (16)	7.3	815 (14)	7.6	-13	127**	140**
<i>Simple</i>	940 (16)	11.7	831 (16)	7.4	817 (13)	7.2	-14*	109**	123**
<i>Difference</i>	15		3^				1^	18	17

Note. \* $p < .05$ ,  $p < .001$ , ^Evidence for null.

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**Table 5***RTs, errors and Stroop effects as a function of onset complexity in Experiment 3.*

<i>Onset</i>	<i>Word Type</i>								<i>Stroop effects</i>			<i>Complex vs. Simple Neutral</i>
	<i>Incongruent</i>		<i>Congruent</i>		<i>Complex Neutral</i>		<i>Simple Neutral</i>		<i>Facilitation</i>	<i>Congruency Effect</i>	<i>Interference</i>	
	<i>Mean (SE)</i>	<i>% Er</i>	<i>Mean (SE)</i>	<i>% Er</i>	<i>Mean (SE)</i>	<i>% Er</i>	<i>Mean (SE)</i>	<i>% Er</i>				
<i>Complex</i>	945 (12)	12.1	829 (12)	7.9	861 (11)	8.1	859 (11)	8.5	32*	116*	84*	2^
<i>Simple</i>	942 (12)	11.3	858 (13)	8.4	860 (11)	8.5	859 (11)	8.1	1^	84*	83*	1^
<i>Difference</i>	3^		29*						31*	32*	1^	

Note. \* $p < .01$ , ^Evidence for null.