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What Stroop tasks can tell us about selective attention from childhood to adulthood

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A rich body of research concerns causes of Stroop effects plus applications of Stroop. However, several questions remain. We included assessment of errors with children and adults ($N = 316$), who sat either a task wherein each block employed only trials of one type (unmixed task) or where every block comprised of a mix of the congruent, neutral, and incongruent trials. Children responded slower than adults and made more errors on each task. Contrary to some previous studies, interference (the difference between neutral and incongruent condition) showed no reaction time (RT) differences by group or task, although there were differences in errors. By contrast, facilitation (the difference between neutral and congruent condition) was greater in children than adults, and greater on the unmixed task than the mixed task. After considering a number of theoretical accounts, we settle on the inadvertent word-reading hypothesis, whereby facilitation stems from children and the unmixed task promoting inadvertent reading particularly in the congruent condition. Stability of interference RT is explained by fixed semantic differences between neutral and incongruent conditions, for children versus adults and for unmixed versus mixed task. We conclude that utilizing two tasks together may reveal more about how attention is affected in other groups.

The Stroop effect refers to our tendency to experience difficulty (conflict or interference) naming a physical colour (we use the term 'hue') when it is used to spell the name of a different colour (the incongruity effect), but not when we simply read out colour words (Stroop, 1935). The RT difference between a neutral condition (e.g., a block of colour or using a hue to spell a non-colour word) and the above conflict condition is a more recent measure of interference, partly because the subtraction of one condition from another acts to reduce or eliminate the influence of general motor responses on the interference measure (Dalrymple-Alford & Budayr, 1966; Hanauer & Books, 2005; Henik, 1996; MacLeod, 1991; Posner & Snyder, 1975; Wright & Wanley, 2003).

Since Stroop's original list-based task, a large variety of studies have used computer versus card presentations, word versus pictorial stimuli, visual versus auditory domain, or list versus single stimuli (Carter, Mintun, & Cohen, 1995; Ehri & Wilce, 1979; Girelli, Lucangeli, & Butterworth, 2000; Henik, 1996; Jongen & Jonkman, 2008; Kindt, Bierman, & Brosschot, 1997; Most, Verbeck Sorber, & Cunningham, 2007; Nichelli, Scala, Vago, Riva, & Bulgheroni, 2005; Wright, Olyedemi, & Gaines, 2015). Tasks have also varied

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according to the vocal versus manual response format (for overview of modality effects, see MacLeod, 1991). On this issue, the typical finding is that Stroop effects are reduced on manual tasks compared with vocal tasks (Klein, 1964; McClain, 1983; Penner *et al.*, 2012).

A common explanation of Stroop effects on the standard task is that reading is done for meaning and is highly over learned from 6 or 7 years (Armengol, 2002; Braet, Noppe, Wagemans, & de Beeck, 2011; Comalli, Wapner, & Werner, 1962; Everatt, Bradshaw, & Hibbard, 1999; Faccioli, Peru, Rubini, & Tassinari, 2008; Fournier, Mazzarella, Riccardo, & Fingeret, 1975; Rand, Wapner, Werner, & McFarland, 1963; Wright, 2014; Wright & Wanley, 2003. On this view, any perceptual evidence that a word is present as part of the stimulus automatically and unavoidably begins activation of that word's meaning (Durston & Casey, 2006), even though the participant attempted only to attend to a different aspect of the stimulus such as its hue (Block, 2005; Brown, Joneleit, Robinson, & Brown, 2002; Henik, 1996). Alternatively, the word can cause difficulty recruiting the response apparatus to output the correct hue name, for example, because words have been associated with saying colours more than have hues (Cohen, McClelland, & Dunbar, 1990; Szucs & Soltesz, 2010). Stroop effects may even reflect both semantic and response conflict in combination (Caldas, Machado-Pinheiro, Souza, Motta-Ribeiro, & David, 2012; Carter *et al.*, 2000). Regardless of which account one prefers, one important implication is that children might be more susceptible to incongruity and interference effects than are adults (MacLeod, 1991; Wright & Wanley, 2003), for example because of differences in how their reading level relates to word meaning, or differences in the extent and control of semantic processes. Investigations comparing child and adult performance might therefore assist diagnosis of certain developmental impairments (e.g., dyslexia – Everatt *et al.*, 1999; Faccioli *et al.*, 2008; Wright, 2014), or even point us to key psychological Stroop processes that may lie beneath those developmental issues themselves (Golden, Espe-Pfeifer, & Wachsler-Felder, 2000; Rand *et al.*, 1963).

Some studies since Stroop's utilize a third condition where the word spells out the same colour as the ink used to write that word (congruent condition – MacLeod, 1991; Tzelgov, Henik, & Berger, 1992). Subtracting congruent from the neutral times gives an index termed facilitation (Dalrymple-Alford & Budayr, 1966; Fagot, Dirk, Ghisletta, & de Ribaupierre, 2009; Posner & Snyder, 1975). Facilitation and interference were thought to be caused by the same semantic process helping versus hindering performance, respectively (MacLeod, 1991). However, more recently MacLeod and MacDonald (2000) proposed a theory wherein Stroop interference results from semantic conflict between colour and word; but facilitation results from inadvertent word-reading errors. The latter carries a benefit rather than a cost because word reading is automatic, obligatory, and much faster than colour naming (Armengol, 2002; Schwartz & Verhaeghen, 2008; Wright & Wanley, 2003).

Glaser and Glaser (1989) argued that facilitation receives far too little investigation, a view that continues to be stated (Chen, Wong, Chen, & Au, 2001; Wright & Wanley, 2003). The relative amounts of facilitation versus interference in children as compared to adults is also of theoretical interest, as this might inform us regarding attentional development or development of automatic reading processes (Everatt *et al.*, 1999; MacLeod & MacDonald, 2000). Unfortunately, developmental Stroop studies have tended not to include a congruent condition alongside neutral and incongruent conditions, resulting in the balance between facilitation and interference in children versus adults largely being overlooked.

Concerning the incongruity effect, Rand *et al.* (1963) found that 5-year-olds are less susceptible than 6-year-olds. They argued that the younger children were less proficient readers and so did not get as drawn towards the word dimension of the stimuli. Indeed, full maturity of reading automaticity may not be reached until around 12 years (Durston & Casey, 2006). This finding also holds for non-word stimuli. For example, using pictures of heads versus bodies of different animals, Nichelli *et al.* (2005) found that RTs only slightly improve from 6 to 8 years, but improvement is relatively steep between 8 and 12 years. Such findings take Stroop beyond being just a word-reading phenomenon, implying that it also derives at least partly from inhibitory/suppression abilities, which appear to be noisy or inconsistent until around 8 years (Comalli *et al.*, 1962; Norman *et al.*, 2011).

In a study of 7- to 11-year-olds on a vocal Stroop task, Bub, Masson, and Lalonde (2006) utilized delta plots of mean accuracy against RTs which had been separated into five bands (quintiles) according to overall response speed (Pratte, Rouder, Morey, & Feng, 2010; Soutschek *et al.*, 2013 for more recent plots of general RT by Stroop interference). A finding of a steeper concaved function for the 7- to 9-year-olds compared with being less steep and straighter for 9- to 11-year-olds, indicated that younger children actually apply more suppression on their responses, although they are slower to respond and produce more errors. Bub *et al.* (2006) concluded that younger children's Stroop performance must therefore reflect another factor – ability to maintain the response set (i.e., keep focus on naming the hues).

However, Bub *et al.* (2006) utilized neutral and incongruent stimuli but not congruent stimuli and so could not investigate the facilitation effect for comparison against interference. Also, as they interleaved colour naming with word reading within each condition (task switching), reading of the word-only stimuli could have increased attention to the to-be-ignored dimension (i.e., the word) on the subsequent (word–hue) stimuli, which might have induced slowing for naming their target hues. So it is not clear how close Bub *et al.*'s (2006) task was to Stroop's original conception of the task.

In a study that extended into adulthood, Norman *et al.* (2011) tested 20- to 65-year-olds on a colour-word Stroop task but in the auditory domain. Here, Stroop RTs decreased with age up to around 60 years and this held for two racial groups analysed separately (Black vs. White). In line with an evidence-based assertion made by MacLeod (1991), no gender differences in Stroop performance were found (for similar conclusions in the visual domain, see Penner *et al.*, 2012). Most *et al.* (2007) did find children showed a greater incongruity effect for gender stereotypic words than for engendered names, whereas adults showed the opposite profile. More generally, this contrast raises the possibility that children versus adults may show opposite profiles on different Stroop tasks, such as those using list versus individual stimuli (Penner *et al.*, 2012).

Validity of Stroop tasks for assessing automaticity

Recently, Dishon-Berkovits and Algom (2000) argue Stroop phenomena derive not from automatic/obligatory processes but rather they derive from incidental correlations between the word and hue across stimuli. See Schmidt and Besner (2008) for extension and refinement of this view to make highly specific predictions on a stimulus-by-stimulus basis. For example, in Stroop's original interference (incongruent) condition by its very definition the word never spells out the colour. When words are negatively correlated with their hues in this way, the participant unconsciously picks up the negative (incongruent condition) or even positive (congruent condition) correlations, and then uses the cues from the words to prepare for the hues which must be named. Using word–word stimuli instead of word–hue stimuli, Dishon-Berkovits and Algom (2000) created positive, negative, and zero correlations and showed that in particular zero correlations all but eliminated Stroop effects. One implication is that Stroop effects are more an artefact of the presentation regime than they are a true reflection of automaticity or our attentional system.

However, in order to create zero correlations, Dishon-Berkovits and Algom (2000) stated they had to avoid using mappings of colour words to hues to create each stimulus; but then they intimated that their findings explain the very colour-hue situations they accepted were difficult to create. Additionally, they did not incorporate a neutral condition, and so interference and facilitation were not addressed. As another issue, perfect positive correlations (congruent condition) should be expected to differ from a neutral condition, more than the difference between negative correlations (incongruent condition) and a neutral condition. In turn, this should lead to facilitation being greater than interference. By contrast, the general finding on this issue is that the facilitation effect is much smaller than the interference effect (Glaser & Glaser, 1989; Ikeda, Okuzumi, & Kokubun, 2013; MacLeod, 1991; Schmidt & Besner, 2008; Sugg & McDonald, 1994).

The above points notwithstanding, studies taking a correlational approach would not necessarily diminish the value of other studies that continue to be based around Stroop's original paradigm (e.g., on confirmation of Stroop validity see Graf, Uttl, & Tuokko, 1995; Klein, Ponds, Houx, & Jolles, 1997). Rather, such (correlational) studies merely permit us to look more closely at how automaticity and attention can be influenced by environmental attributes. For example, Dishon-Berkovits and Algom (2000) theory does not take away from well established Stroop-based findings such as regarding clinical anxiety, schizophrenia depression, phobias, attention deficit hyperactivity disorder (ADHD), dyslexia, post -traumatic stress disorder, racial attributions, patients feigning versus not feigning impairments from brain injuries or even just changes in Stroop effects with age (Arentsen *et al.*, 2013; Cannon, 2003; Comalli *et al.*, 1962; Everatt, Warner, & Miles, 1997; Mathews, Mogg, Kentish, & Eysenck, 1995; Soutschek *et al.*, 2013; Wright, 2014; Wright, Olyedemi *et al.*, 2015; Wright, Peters, Wright, Osborn, & Kumari, 2015; Wright & Wanley, 2003). Rather, they simply introduce into our explanations differences within or between each of these groups according to the differing ways the implicit correlations play out in their responses.

Potential utility of interference effects across different designs

Earlier we outlined some of the variability of designs which each constitute Stroop tasks. Given this wide variety, some investigators question not only whether Stroop effects differ from childhood to adulthood, but also whether interference is identical across different tasks (Ikeda *et al.*, 2013; Kindt *et al.*, 1997). Penner *et al.* (2012) tested adults on a list Stroop task using vocal responses versus a computer-based trial-by-trial format with manual responses. In line with prior research with children (Kindt *et al.*, 1997), the interference effect was far larger for the list format (306 ms vs. 119 ms, respectively). When they contrasted adults against children of mean age 11 years, Penner *et al.* (2012) found children's interference was higher than for adults with the list format but much lower than adults on the single-trial format (Arsalidou, Agostino, Maxwell, & Taylor, 2013; Lorsbach & Reimer, 2011). However, here it is not clear how far the findings were due to the two groups, the single versus list format or using vocal compared with manual responses.

When Ikeda *et al.* (2013) investigated age-related trends on a manual colour-word Stroop task with 5- to 12-year-olds and young adults, they found no statistical interaction between Stroop condition and age group. This suggests that interference may not alter with age, although it should be noted that, by contrasting congruent against incongruent condition, Ikeda *et al.* (2013) may have indexed combined interference and facilitation, rather than isolating only interference (Braet *et al.*, 2011). Notwithstanding, taking Ikeda *et al.*'s (2013) findings together with Penner *et al.*'s (2012) findings suggests that the question of whether Stroop interference does or does not alter from childhood to adulthood is in need of further research.

Finally here, some studies use blocks of unmixed trials (e.g., block 1 contains only congruent trials – Arentsen *et al.*, 2013; Ehri & Wilce, 1979; Penner *et al.*, 2012). Other studies utilize a mixed-trial format (e.g., each block contains some congruent, neutral, and incongruent trials – Carter *et al.*, 1995; MacLeod & Bors, 2002; Mead *et al.*, 2002). In a recent study based on unmixed conditions, Wright and Wanley (2003) demonstrated that children exhibit a much greater facilitation effect than do adults, and yet child–adult interference effects are indistinguishable. However, unmixed trials might allow positive and negative correlations to assist responses, even when correlations are not computed consciously (Dishon-Berkovits & Algom, 2000; Schmidt & Besner, 2008). In the limit, this issue can be investigated by comparing mixed versus unmixed conditions, which are as identical as possible in all other respects. Of potentially greater significance, such a comparison could reveal differences between children and adults which have not yet been demonstrated. In turn, such differences would pave the way for the use of dual/composite Stroop tasks (e.g., mixed vs. unmixed conditions) to reinvestigate the associations between Stroop performance and the presence, severity, or even feigning of various impairments (Arentsen *et al.*, 2013; Cannon, 2003; Golden *et al.*, 2000).

Aims of the present study

This study concerned both adults and children. As the incongruity effect may reach its maximum at up to 8 years (Comalli *et al.*, 1962; Nichelli *et al.*, 2005; Rand *et al.*, 1963), this was our lower age limit. Then, as Durston and Casey (2006) showed children's reading automaticity is reached at around 12 years, this set the maximum age for our children. Then, Stroop effects have been shown to improve more consistently in 9- to 11-year-olds than in 7- to 9-year-olds (Bub *et al.*, 2006; Nichelli *et al.*, 2005). With this in mind, we decided to work with children in the range of 9–11 years. Aside from this consideration, our study had three main aims.

First, in contrast to Ikeda *et al.* (2013) and Penner *et al.* (2012) whose tasks were largely in the manual domain, Stroop's original task used verbal responses. Thus, vocal tasks in some sense may have the strongest claim to being Stroop tasks (Golden *et al.*, 2000; MacLeod, 1991; MacLeod & MacDonald, 2000). However, since one is hard-pressed to identify a robust child–adult study that assesses the Stroop interference effect (as distinct from the incongruity effect) on the more traditional vocal task, our first aim was to provide such a child–adult comparison.

Second, we note that child–adult differences could be due to mistargeting Stroop phenomena or to mistimings (e.g., because children tend more often to self-correct their errors – Comalli *et al.*, 1962; Golden *et al.*, 2000; Imbrosciano & Berlach, 2005; Rand *et al.*, 1963). Therefore, a second aim was to obtain highly representative Stroop times perhaps particularly for children. We did this by taking RT for only correct trials, doing so on a stimulus-by-stimulus basis (Barkley, Grodzinsky, & DuPaul, 1992; Bub *et al.*, 2006; Carter *et al.*, 1995; Kindt *et al.*, 1997).

Third, we aimed to determine whether performance on a mixed versus unmixed Stroop task would reveal any opposing trends in children versus adults, which were of potential utility in developmental or impairment research. Most *et al.* (2007) showed that contrasts between two different Stroop tasks can indeed yield insights that are more difficult to glean than with a single task (Penner *et al.*, 2012). Our comparison of an unmixed trials task with a mixed trials task was in terms of individual conditions plus interference and facilitation. Our rationale was that mixed presentations but perhaps not unmixed presentations prevent participants being induced to read the words before responding to the hue of each stimulus (because words do not help in the incongruent condition or the neutral condition). Further, our use of a neutral condition in the mixed task disrupted any negative correlations or positive correlations that might feature in the congruent and incongruent conditions because neutral words were not related to hues.

Method

Participants

There were 316 participants of whom 150 were adults (mean age = 23.9 years, *SD* = 5.35, range 17–45 years), with 66 being female. The remaining 166 participants were children (mean age = 10.5, *SD* = 0.58, range 9.41–11.37 years), with 82 being female. The adults were volunteers from a local university, and the children were from several schools in the local area. Participants and their educational establishments reported them having no issues with colour-blindness or educational problems, and each had normal or corrected-to-normal visual acuity.

Approximately half of each group was assigned to the unmixed trials task with the other half assigned to the mixed trials task. This resulted in 81 children for the unmixed task, 40 female (mean age = 10.5 years, *SD* = 0.58) and 41 males (mean age = 10.6, *SD* = 0.49). There were 85 children on the mixed task, 42 females (mean age = 10.7, *SD* = 0.56) and 43 males (mean age = 10.4, *SD* = 0.66). There were 74 adults on the unmixed task, 37 females (mean age = 24.9, *SD* = 4.34) and 37 males (mean age = 24.1, *SD* = 4.74). Finally, there were 76 adults on the mixed task, 29 females (mean age = 24.8, *SD* = 7.50) and 47 males (mean age = 22.3, *SD* = 4.67).

Materials

The Stroop task was presented on a Toshiba Satellite Pro Pentium 4 laptop connected to an external keyboard and a 19-inch flat screen Pro-View monitor. For Stroop stimuli, we used good exemplars of red, blue, yellow, and green for the hue dimension (MacLeod & Bors, 2002; Olatunjia, Sawchuk, Lee, Lohr, & Tolin, 2008). The spelt word of each colour constituted the to-be-ignored dimension. Hue and word combined to make two of our three Stroop conditions (congruent and incongruent).

The third condition was the neutral condition. Many investigators advocate the use of neutral words rather than just patches of colour, because then the only difference between each of the three conditions is the meaning of the distractor word (Augustinova & Ferrand, 2012; Mead *et al.*, 2002). In our case, we used the words ‘car’, ‘sheep’, ‘plug’, and ‘jigsaw’ in place of the four colour words (see also Hanauer & Books, 2005). Following Ehri and Wilce (1979), these words are well known to children as well as adults (see Olatunjia *et al.*, 2008 on lack of word frequency effects). Also, they are similar to the colour words in syllabic and phonological structure, with the deliberate exception of onset (Rayner & Posnansky, 1978). However, they were not directly associated with any specific colour and also were not semantically related to each other (Carter *et al.*, 1995).

As an example of the neutral condition, we might use blue to write the word 'sheep' (the correct response is 'blue').

For each stimulus of any condition, the word was presented on a low-intensity white background (following Braet *et al.*, 2011). It was printed in colour in a font equivalent to Times New Roman 32 point. Colour-naming times were collected on a trial-by-trial basis, with responses collected using a headset microphone.

Each of the two tasks was divided into seven blocks with 48 trials per block. The first block was common to both tasks and comprised 16 colour words, 16 neutral words, and 16 rectangular patches of colour, presented in a pre-randomized order. This was discarded after serving to determine whether a participant had anomalous colour perception or unusual difficulty reading the colour words or neutral words (e.g., colour-blindness or dyslexia), which might interfere with performance. The remaining blocks differed depending on whether the participant sat the unmixed trials task or the mixed trials task. For the unmixed task, block 2 contained 48 congruent stimuli. These were presented in a random order that was the same for each participant. Block 3 was similar apart from consisting of 48 neutral words and block 4 the same but consists of incongruent words. Blocks 5, 6, and 7 contained neutral, incongruent, and congruent stimuli, in the same way. Thus, there were two blocks of each stimulus type, with the first three blocks given in a different order to the second three blocks. Alternating blocks in this way is common in Stroop research (Pratte *et al.*, 2010), serving to balance out practice effects without overburdening our child participants.

For the mixed task, block 2 contained 16 congruent, 16 neutral, and 16 incongruent stimuli in a pre-randomized order. Here, each of the four possible congruent combinations of word and hue needed to be repeated four times in order to achieve all 16 required stimulus slots, with each of the 16 combinations of neutral word and hue repeated once. For incongruent stimuli, the first 12 stimulus slots were filled with each of the 12 possible incongruent combinations of word and hue, with the remaining four required slots achieved by randomly assigning four of the possible 12 combinations to each of the three Stroop blocks (blocks 2–4).

Blocks 5–7 were then constructed in the same way as blocks 2–4, apart from containing newly randomized stimuli. Thus, whether a participant sat the unmixed task or the mixed task, he or she responded to a total of 96 congruent stimuli, 96 neutral stimuli and 96 incongruent stimuli. Importantly, across all 96 stimuli of a given category, each combination of word and hue occurred precisely the same number of times as any other combination in its respective stimulus category (congruent, neutral or incongruent), with this the case for each block of the mixed and unmixed tasks.

Design

The experiment used a mixed factorial design with three main independent variables. The first was Group, referring to adults or children, respectively. The second was Task, which referred to whether we used the unmixed task or the mixed task. The third variable was a repeated factor of Condition, referring to the congruent, neutral, and incongruent trials, respectively. There were two main dependent variables, RT and number of errors.

Procedure

Upon being briefed and giving consent (in the case of children, the parents and class teacher had also given consent), the participant was seated in front of the computer about

60 cm from the screen (Penner *et al.*, 2012). For adults, testing took place in a psychology laboratory setting. For children, this was a fairly quiet location chosen by the school (e.g., an adjoining classroom or staffroom).

Participants were informed that they would see words written in various colours (red, blue, green, or yellow). They had to name out loud the colour the word was written in, ignoring whatever the word spelt out. Following long-standing standard response instructions (MacLeod & MacDonald, 2000; Rand *et al.*, 1963), participants were informed of the importance of keeping errors low, but also of responding to the hues as quickly as they were able. RTs were recorded via a headset microphone attached to the computer, with its input sensitivity adjusted to suit the participant being tested.

Before beginning the test sessions, participants were given practice on an all-incongruent block (unmixed task) or a randomized block (mixed task). Practice came in the form of a short block of 12 trials. A trial began with a fixation cross, followed by a delay randomly varying between 500 and 1,500 ms. This was followed by presentation of the stimulus. Participants named the ink colour, ignoring the word. As soon as the response for the current trial was registered, there was a 500-ms delay and then the next trial was begun. On completing the practice trials, each participant sat the seven blocks of their respective task, separated by short breaks. Both for child and adult participants, errors were noted by a researcher seated behind the participant, as is common in Stroop-like research (Bub *et al.*, 2006). Although the presence of a bystander has been shown to reduce interference in adults (Augustinova & Ferrand, 2012), there is little empirical evidence on this issue regarding children. Furthermore, our procedure was designed to give priority to issues such as children alone in such an experimental environment becoming anxious or demotivated. Of relevance, our entire procedure took 20–25 min.

Results

For each task, we calculated the median RT for the congruent, neutral, and incongruent conditions (following Mead *et al.*, 2002). This reduces any spurious effects of near-zero or outlier values, whilst at the same time allowing any genuine tendencies (such as differential tendencies of the groups towards more above-mean values in certain conditions) to be expressed. Any trial receiving an error response was excluded from the RT calculations. Here, we defined an error response as one where the vocalization that triggered the computer timer was anything other than the correct response to a given trial (Carter *et al.*, 2000; Kindt *et al.*, 1997; Rand *et al.*, 1963). The data on errors were summarized similar to RT, apart from counting the total number of errors for a given task or condition, rather than using the median.

Each RT and error analysis of variance (ANOVA) reported below was first conducted including Gender as an additional factor. However, as there were no main effects or interaction effects involving gender, neither for RT nor for errors (each $F < 2.88, p > .08$), and as all main effects and interaction effects were preserved with gender excluded, we present below each analysis with gender excluded.

Effects of congruity, neutrality, and incongruity

Our first analysis concerned RTs. These were analysed using a three-way ANOVA with factors of Task, Group, and Condition. Table 1 shows children responded to trials around 140 ms slower than adults, $F(1, 308) = 77.57, p < .01, \eta_p^2 = .20$. Concerning Task, the

Table 1. Summary of RT by group and condition

	Congruent	Neutral	Incongruent	Average
Child unmixed	631 (15)	758 (16)	862 (18)	750 (15)
Child mixed	786 (15)	858 (15)	961 (17)	869 (15)
Child both	708 (10)	808 (11)	912 (12)	809 (10)
Adult unmixed	576 (16)	628 (17)	726 (18)	643 (16)
Adult mixed	633 (16)	673 (17)	776 (19)	695 (16)
Adult both	605 (11)	651 (12)	751 (13)	669 (11)
Combined unmixed	603 (11)	693 (11)	794 (13)	697 (11)
Combined mixed	710 (11)	766 (11)	869 (12)	782 (11)
Combined both	657 (8)	729 (8)	832 (9)	739 (7)

Note. Cells give mean RTs for each group and condition. Numbers in parentheses represent standard errors of RTs.

unmixed task led to RTs 85 ms faster than the mixed task, $F(1, 308) = 28.43$, $p < .01$, $\eta_p^2 = .08$. Conditions showed the typical Stroop profile, with the congruent condition faster than the neutral condition and the incongruent condition slowest. The overall tendency was statistically significant, $F(2, 616) = 540.56$, $p < .01$, $\eta_p^2 = .63$.

Considering two-way interactions, there was a statistically significant tendency for the overall difference between children and adults to increase from the congruent condition, through the neutral condition to the incongruent condition, $F(2, 616) = 18.16$, $p < .01$, $\eta_p^2 = .05$. Regarding Task times Condition, the difference between unmixed and mixed tasks was greater in the congruent condition than in neutral and incongruent conditions, $F(2, 616) = 6.34$, $p < .01$, $\eta_p^2 = .02$. For the interaction between Group and Task, the large overall RT difference between the unmixed and mixed tasks significantly declined from childhood to adulthood, $F(1, 308) = 4.30$, $p = .03$, $\eta_p^2 = .01$. The three-way interaction between Group, Task, and Condition was also significant, $F(2, 616) = 2.96$, $p = .05$, $\eta_p^2 = .01$. This interaction is explained in Figure 1 (top).

Having analysed the Stroop data in terms of RT for correct responses, we now repeated the same analysis for the error data. Table 2 shows that children made more than twice the number of errors compared with adults, $F(1, 308) = 60.71$, $p < .01$, $\eta_p^2 = .16$. Fewer errors occurred in the congruent condition than the neutral condition, and more errors occurred in the incongruent condition than the neutral condition, $F(2, 616) = 222.69$, $p < .01$, $\eta_p^2 = .42$. However, although there were slightly more errors on the mixed task than the unmixed task (overall difference = 0.2), this difference did not approach statistical significance, $F(1, 308) < 1$.

For the two-way interaction between Group and Condition, the difference between children and adults for number of errors increased from the congruent condition through the neutral and to the incongruent condition, $F(2, 616) = 27.24$, $p < .01$, $\eta_p^2 = .08$. For Group times Task, children made more errors on the unmixed task than the mixed task, with adults doing the converse, $F(1, 308) = 10.62$, $p < .01$, $\eta_p^2 = .03$.

For the Task times Condition interaction, no significant trend emerged, $F(2, 616) = 1.93$, $p = .14$, $\eta_p^2 < .01$. However, there was a statistically significant three-way interaction between Group, Task, and Condition, $F(2, 616) = 28.80$, $p < .01$, $\eta_p^2 = .08$. This interaction is explained in Figure 1 (bottom).

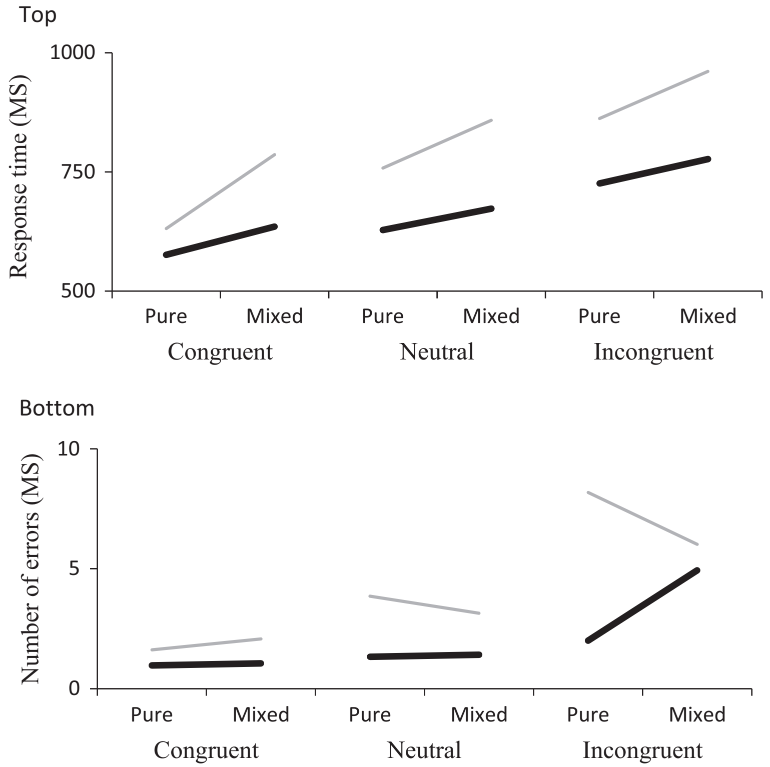

Figure 1. The three-way interaction for RT (top) and errors (bottom). For each condition, light (thin grey) line denotes children and heavy (thick black) line denotes adults. Top – this shows that the three-way interaction was caused by children's unmixed performance moving away from that of adults, at the same time as general increases in RT as we move from the congruent condition to the neutral and incongruent conditions. Bottom – this shows that the relative slope of the lines systematically becomes less positive (unmixed end progressively widens), as we go from congruent through to incongruent condition.

Interference and facilitation effects

A summary of interference and facilitation for RT and errors is given in Table 3. The data were analysed using two-way between-subjects ANOVAs, two for interference (RT vs. errors) and likewise for facilitation. The factors in each analysis were Group and Task. Significant interaction effects were followed up by *post hoc* analyses, with the Bonferroni method used to correct for multiple comparisons.

For interference RTs (Table 3), overall performance on the unmixed versus mixed task did not significantly differ, $F(1, 308) < 1$. Children's *interference* RT was only around 3 ms greater than adults', with this difference again not significant, $F(1, 308) < 1$. As intimated by Figure 2 (top right), any tendency towards a two-way interaction between group and task was also non-significant, $F(1, 308) < 1$.

For interference errors, overall number of errors on the mixed task did not significantly differ from the unmixed task, $F(1, 308) = 2.88$, $p = .09$, $\eta_p^2 < .01$. However, children made almost twice the errors compared with adults, $F(1, 308) = 13.49$, $p < .01$, $\eta_p^2 = .04$. Concerning a two-way interaction (Figure 2, bottom right), the tendency for children to make more interference errors on the unmixed task than the mixed task but adults to make more errors on the mixed task than the unmixed task was statistically significant,

Table 2. Summary of number of errors by group and condition

	Congruent	Neutral	Incongruent	Average
Child unmixed	3.23 (0.40) 3.36%	7.70 (0.60) 8.02%	16.35 (0.97) 17.04%	9.09 (0.55) 9.48%
Child mixed	4.15 (0.39) 4.32%	6.29 (0.58) 6.54%	12.04 (0.95) 12.54%	7.49 (0.53) 7.80%
Child both	3.69 (0.27) 3.84%	6.99 (0.41) 7.28%	14.19 (0.68) 14.78%	8.29 (0.38) 8.64%
Adult unmixed	1.93 (0.41) 2.02%	2.65 (0.62) 2.76%	4.00 (1.01) 4.16%	2.86 (0.57) 2.98%
Adult mixed	2.11 (0.42) 2.20%	2.83 (0.63) 2.96%	9.87 (1.03) 10.28%	4.94 (0.58) 5.14%
Adult both	2.02 (0.29) 2.10%	2.74 (0.44) 2.86%	6.93 (0.72) 7.22%	3.90 (0.41) 4.06%
Combined unmixed	2.58 (0.28) 2.68%	5.17 (0.43) 5.38%	10.18 (0.70) 10.60%	5.98 (0.40) 6.22%
Combined mixed	3.13 (0.28) 3.26%	4.560 (0.43) 4.76%	10.95 (0.70) 11.40%	6.21 (0.39) 6.48%
Combined both	2.86 (0.20) 2.98%	4.87 (0.30) 5.08%	10.56 (0.49) 11.00%	6.10 (0.28) 6.36%

Note. Cells give mean number of (raw) errors plus their percentage equivalent. Numbers in parentheses represent standard errors of each raw value.

Table 3. Summary of facilitation and interference by group

	RT facilitation	RT interference	Errors facilitation	Errors interference
Child unmixed	127 (9)	104 (10)	4.47 (0.48) 4.66%	8.65 (0.80) 9.00%
Child mixed	72 (9)	103 (10)	2.13 (0.47) 2.22%	5.75 (0.78) 5.98%
Child both	99 (6)	103 (7)	3.30 (0.33) 3.44%	7.20 (0.56) 7.50%
Adult unmixed	52 (9)	98 (10)	0.72 (0.50) 0.74%	1.35 (0.83) 1.40%
Adult mixed	40 (10)	104 (11)	0.73 (0.51) 0.76%	7.03 (0.85) 7.32%
Adult both	46 (7)	100 (7)	0.72 (0.36) 0.76%	4.19 (0.59) 4.36%
Combined unmixed	89 (6)	101 (7)	2.59 (0.34) 2.70%	5.00 (0.58) 5.20%
Combined mixed	56 (6)	103 (7)	1.43 (0.34) 1.48%	6.39 (0.57) 6.66%
Combined both	73 (4)	102 (5)	2.01 (0.24) 2.10%	5.70 (0.41) 5.94%

Note. Cells give relative mean RTs, or relative number of errors plus their percentage equivalent. Numbers in parentheses represent standard errors of each value.

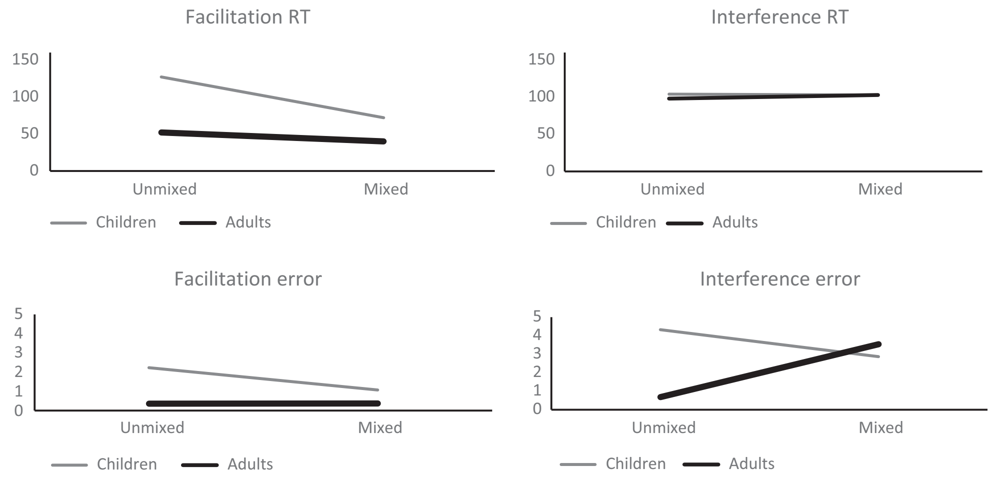

Figure 2. Facilitation and interference for RT (top) and errors (bottom). For each effect, light (thin grey) line denotes children and heavy (thick black) line denotes adults. Top – this shows that for RT, children's interference was indistinguishable from adults' as one moves from unmixed to mixed task; but their facilitation profiles became highly distinct, although beginning to converge in the mixed task. Bottom – Unlike for RT, the child–adult interference and facilitation error profiles were very similar, and for each profile, the progressive convergence as we move from unmixed to mixed task was driven by children rather than adults.

$F(1, 308) = 27.41, p < .01, \eta^2_p = .08$. Because we had expectations regarding children's comparative performance on the two tasks, *post hoc* comparisons were one-tailed (see also Soutschek *et al.*, 2013). Our adjustment of significance levels for two comparisons replaced the .05 alpha level with .025.

An independent samples *t*-test for children showed their interference errors were significantly greater in the unmixed task ($N = 166, df = 164, t = 2.07, p < .025$). Adults' greater number of errors on the mixed task also was statistically significant ($N = 150, df = 148, t = -8.19, p < .01$). Thus, the two-way interaction for interference errors was driven both by the child tendency and the opposite adult tendency. The right half of Figure 2 permits ready appreciation of the contrast between this interaction versus the earlier lack of an interaction we found for interference RT.

Turning to facilitation RTs (Table 3), the unmixed task led to significantly greater facilitation than the mixed task, $F(1, 308) = 12.47, p < .01, \eta^2_p = .03$. Also, children's facilitation was over twice the magnitude of adults' facilitation, $F(1, 308) = 31.59, p < .01, \eta^2_p = .09$. There was a statistically significant two-way interaction, with relatively high facilitation for children in the unmixed task compared with the mixed task, significantly reduced in adulthood, $F(1, 308) = 4.44, p = .03, \eta^2_p = .01$. *Post hoc* tests showed children's greater facilitation RTs in the unmixed task was statistically significant ($N = 166, df = 164, t = 3.34, p < .01$). However, although for adults the tendency was in the same direction as for children here, adults' difference in RT between unmixed and mixed tasks was not significant ($N = 150, df = 148, t = 1.38, p > .05$).

Facilitation errors (Table 3) on the unmixed task were significantly larger than on the mixed task, $F(1, 308) = 5.56, p = .01, \eta^2_p = .01$. Children showed significantly more facilitation than adults, $F(1, 308) = 27.38, p < .01, \eta^2_p = .08$. Additionally, there was a significant two-way interaction between Group and Task, with children showing over twice the facilitation effect on the unmixed task compared with the mixed task, but no task difference for adults, $F(1, 308) = 5.67, p = .01, \eta_p^2 = .01$. *Post hoc* analysis confirmed children showed greater facilitation errors in the unmixed task ($N = 166$, $df = 164$, $t = 2.64$, $p < .01$). However, for adults there was no statistically significant difference between unmixed and mixed tasks ($N = 150$, $df = 148$, $t = -0.07$, $p > .05$). The similar interaction profiles for facilitation RT and errors are characterized in the left half of Figure 2.

Variations in interference and facilitation

Our final set of analyses considered facilitation and interference as a function of overall response speed (for similar conception see Bub *et al.*, 2006). Specifically, we were interested in the possibility that our above finding that facilitation is greater in children than adults was not so much due to a qualitatively different Stroop profile for children versus adults, but rather was due simply to children responding more slowly than adults on Stroop tasks. We could then interpret our analysis in the context of an analogous analysis for interference, especially as we did not find any significant overall difference between children and adults regarding interference RTs.

On this occasion, we confined the following analyses to RT mainly because of the greater range of scores and greater stability of means in our RT data. For these analyses, we averaged across participants' three Stroop conditions to give a fairly stable estimate of their general RT, doing this separately for each group on each task. We then used two methods of considering whether longer general response speed is associated with greater facilitation and indeed interference. One was statistical and the other was graphical (see Bub *et al.*, 2006; Pratte *et al.*, 2010 for a discussion of this method).

Taking the graphical method first, delta plots can be computed on a within-subject basis (Soutschek *et al.*, 2013). However, because here we were interested in variations between groups (children vs. adults), we plotted variations between participants and how these relate to facilitation and interference. We therefore computed our plots on a participant by participant basis. We categorized participants' overall (i.e., mean) speed of responding across congruent, neutral, and incongruent conditions, into successive quartiles, doing so separately for each composite of group and task. We then calculated the mean for each quartile category. This allowed us to plot very basic delta functions using only four X, Y coordinates. Other studies have used from 10 down to five categories (Bub *et al.*, 2006; Pratte *et al.*, 2010; Soutschek *et al.*, 2013). However, we elected to use quartiles here because using more than four points would reduce the number of participants contributing to each point and would have rendered our plots less stable.

The delta plots of overall speed of responding (X-axis) against facilitation RT (Y-axis) are given in Figure 3, with corresponding functions for interference RTs depicted in Figure 4. The basic idea is that if facilitation increases with overall speed of responding, we should observe a function that is essentially positive and linear. Then, if facilitation is dominated more by strong response suppression, we should observe a single concave aspect to the function (Pratte *et al.*, 2010).

For the unmixed task, the function for children (Figure 3, top left) showed no systematic or straight forward relationship between size of facilitation RT and overall speed of responding. It may be that children essentially separate out into two subgroups (those with low facilitation and those with high facilitation), with the relationship between facilitation versus overall speed of responding being shifted leftwards (the rise and fall are repeated at longer overall RTs) for the high facilitation group. Children's

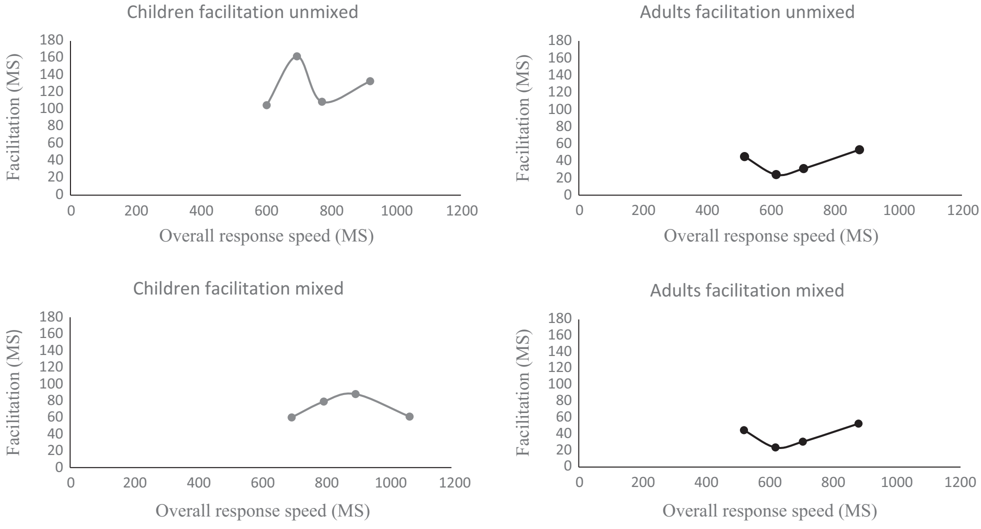

Figure 3. Plot of children's (left graphs) and adults' (right graphs) overall speed of responding against facilitation RT. This shows that children's facilitation RTs did not tend to increase systematically with increase in quartile category, neither on the unmixed or the mixed task, whereas for adults facilitation first decreased slightly before increasing more steadily with quartile for both tasks (U-shaped function).

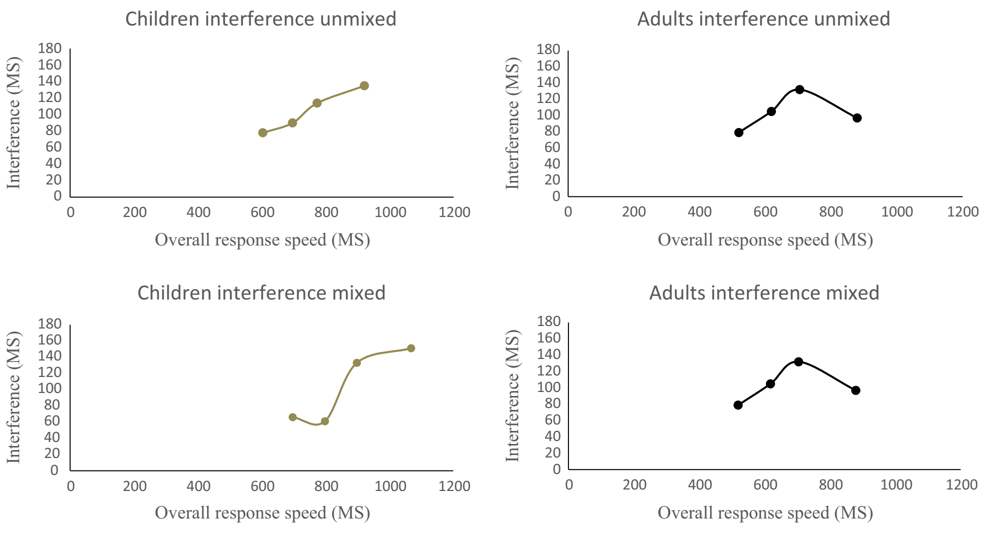

Figure 4. Plot of children's (left graphs) and adults' (right graphs) overall speed of responding against interference RT. This shows that children's interference varied systematically with quartile in the unmixed and mixed tasks, although in the mixed task there was an anomaly in quartile 1. For adults, the interference function was an inverted 'U' (inverse of their facilitation functions), and their interference functions were identical on the unmixed and mixed tasks. [Colour figure can be viewed at wileyonlinelibrary.com]

unmixed profile contrasts with adults', for whom the function appeared essentially concaved but dominated by a positive slope (a 'U' but with a higher right hand tail). For adults then, larger facilitation RTs were related to faster speeds for giving responses; but as speed of responding became very slow, facilitation began to increase again. This child versus adult contrast for the unmixed task was essentially repeated for the mixed task (Figure 3, bottom left vs. right). Our interpretation of these four functions for facilitation is that facilitation RT in children may be caused by (or at least dominated by) a different source to that in adults, with adults' facilitation actually involving more response suppression.

Turning to the plots for interference for the unmixed task (Figure 4), the function for children's unmixed task suggested a more or less linear increase in facilitation RT with increase in overall speed of responding. The slight departure was that quartile 3 was slightly raised, producing a very slight overall convexed function. This compares to the unmixed task function for adults which now resembled an inverted 'U' (i.e., very much more convexed). For interference on the mixed task, the delta function for children seemed rather non-systematic; but this was due solely to a negative slope from quartile 1 to quartile 2 (possibly due to children sometimes giving correct responses by chance – a greater tendency to guess for fast responses in the incongruent condition). Other than this, the function was similar to that for children's unmixed task. However, for adults, the interference function exactly mirrored the inverted 'U' function previously seen for adults on their unmixed task. The overall picture for interference from these basic delta plots is therefore that children's interference on both tasks was dominated by a tendency for increasing interference to be associated with longer RTs; but adults' function showed increasing interference which only decreased for the very longest response speeds, both for unmixed and mixed tasks.

Turning to our second analytical method, statistically analysing overall speed of responding according to facilitation/interference is noted to be difficult (Pratte *et al.*, 2010). To make this more tractable, we conducted our analyses using the quartile categories (1 through 4) rather than the means of these categories, so that we could constitute levels of a single 'quartile' factor. The means for facilitation and interference for the four quartiles according to each composite of group and task are presented in Table 4.

A one-way ANOVA for facilitation RT was conducted separately for each of our four composites of group and task. Each ANOVA used the factor of overall_response_quartile_category_RT having four levels corresponding to quartiles 1 through 4 (hereinafter referred to as 'quartile'). This factor was derived from the relevant sample and task values. For the facilitation ANOVA for children on the unmixed task, the main effect of quartile

Table 4. Summary of facilitation and interference by quartile category

	Q1 cat	Q2 cat	Q3 cat	Q4 cat	Overall
Facilitation					
Child unmixed	105 (29)	161 (29)	108 (29)	132 (28)	127 (14)
Child mixed	60 (16)	79 (15)	88 (16)	61 (15)	72 (8)
Adult unmixed	47 (10)	26 (9)	59 (8)	71 (9)	51 (4)
Adult mixed	45 (14)	24 (16)	31 (14)	53 (13)	38 (7)
Interference					
Child unmixed	77 (29)	89 (29)	114 (29)	134 (28)	104 (14)
Child mixed	65 (16)	60 (15)	133 (16)	151 (15)	102 (8)
Adult unmixed	61 (9)	97 (8)	99 (7)	123 (8)	95 (4)
Adult mixed	79 (20)	105 (23)	132 (20)	97 (19)	103 (10)

Note. Q1 cat refers to the category for the first quartile. Numbers in parentheses represent standard errors of each value.

was not statistically significant, $F(3, 77) < 1$. For the mixed task, the main effect of quartile was again not statistically significant, $F(3, 81) < 1$. Thus, for children, the size of facilitation RT is not to be explained in terms of their overall speed of responding, neither for the unmixed or the mixed task.

For facilitation for adults on the unmixed task, the main effect of quartile was now significant, $F(3, 70) = 4.38$, $p < .01$, $\eta_p^2 = .16$. However, for adults on the mixed task there was no significant main effect of quartile, $F(3, 72) < 1$. So for facilitation RT, children's performance by quartile did not resemble adults on the unmixed task; and no effects of quartile were found for children or adults on the mixed task. Thus, our data do not support the thesis that simple differences in speed of responding explain our earlier findings of greater general facilitation RT for children compared with adults.

Turning to interference (Table 4, bottom), children's unmixed task showed no significant main effect of quartile, $F(3, 77) < 1$. By contrast, for children on the mixed task, there was now a significant main effect of quartile, $F(3, 81) = 8.29$, $p < .01$, $\eta_p^2 = .24$.

For adults' interference on the unmixed task, the main effect of quartile was significant, $F(3, 70) = 8.12$, $p < .01$, $\eta_p^2 = .26$. However, for adults on the mixed task, quartile was not significant, $F(3, 72) = 1.12$, $p > .05$, $\eta_p^2 = .04$. So for interference RT according to overall speed of responding, children's profile was in some sense opposite to that of adults; in so far as quartile can explain variations in children's interference RT for the unmixed task, but for adults it explains variations for the mixed task instead.

Discussion

Across two block designs (mixed task vs. unmixed task), we reconfirmed the expected Stroop profile for RT (MacLeod, 1991). In line with this, response accuracy was highest for the congruent condition and lowest for the incongruent condition (Caldas *et al.*, 2012; Mead *et al.*, 2002; Wright & Wanley, 2003). There were no main/interaction effects for RT or errors involving gender for conditions or for interference/facilitation (Block, 2005; Imbrosciano & Berlach, 2005; MacLeod, 1991; Most *et al.*, 2007). Our accuracy levels were similar to those of Penner *et al.* (2012), who reported that 11-year-old children made around 12% errors on the incongruent condition, with adults making around 8% errors, and to those of Bub *et al.* (2006) who reported that children of around 9 years made 18% errors in the incongruent condition. Our own estimates were 15% for 9- to 11-year-olds and 7% for adults. Below, we present a discussion in terms of Stroop conditions, interference estimates, the facilitation effect, and theoretical accounts that might fit our data.

Condition differences according to age group

It was no surprise to find children responded slower on all six conditions constituting our mixed and unmixed tasks (Ikeda *et al.*, 2013; Lorsbach & Reimer, 2011). Maybe development simply involves a general increase in ability to respond verbally to stimuli under speeded conditions (Schwartz & Verhaeghen, 2008). However, it is just as likely that more proficient readers (i.e., adults) unconsciously or inadvertently read the word dimension of the stimulus faster, so leaving more time for suppression of the response associated with the word and subsequent selection of the response associated with the hue (Ehri & Wilce, 1979; Faccioli *et al.*, 2008).

We consider that such general slowing accounts do not readily explain why children, when contrasted with adults, were disproportionately slowed in some conditions over others. Perhaps children's less mature attentional system causes greater slowing and more errors if a condition necessitates stronger suppression (Bub *et al.*, 2006; Protopapas, Archonti, & Skaloumbakas, 2007). That said, the simultaneous decrease in number of errors from childhood to adulthood supports the additional contention that a second possible factor improving during adolescence (the time period separating our children from our adults) is ability to keep one's attention focussed on the task set and/or quickly recover from such influences (Imbrosciano & Berlach, 2005). Note, in a school context, inhibiting distractions and outside influences plus recovering from such influences is often termed 'remaining on task' (Golden *et al.*, 2000). Our finding that children made over twice the number of errors compared with adults overall, doing so disproportionately in the incongruent condition, further supports this interpretation (Helland & Asbjørnsen, 2000; Lorsbach & Reimer, 2011).

Effects of unmixed versus mixed tasks

Although our unmixed task led to faster overall responses than the mixed task, there was no overall difference in errors. There were also no differences in errors on these tasks according to condition (Ikeda *et al.*, 2013; Schoot, Licht, Horsley, & Sergeant, 2000). By contrast, for RT we found that the task difference was much greater in the congruent condition than in neutral and incongruent conditions. The implication is that there is something about an all-congruent condition that leads participants to be able to improve their speed of responding, something that is greatly reduced on congruent trials if these occur within the mixed task.

Before discussing this issue further, we consider task differences according to group. Here, children responded faster on the unmixed task than the mixed task, although slower than adults in both cases. However, they made more errors on the unmixed task than the mixed task, but adults did the converse (Helland & Asbjørnsen, 2000). This may suggest that children and adults had tended towards somewhat different strategies (Most *et al.*, 2007). Specifically, children may have felt able to respond faster on the task having stimuli of only one condition in each block; but then they seemed to tend to lose concentration because of responding so fast in that condition, as compared to their maximum speed (Imbrosciano & Berlach, 2005).

So, this may be further evidence that child performance is governed (i.e., limited) largely by difficulties they have maintaining the response set, irrespective of their ability to efficiently suppress the unattended dimension. Compared with children, adults may have found maintaining the task set less challenging, which is essentially a top-down strategic process (Carter *et al.*, 2000). But when the distracting (word) dimension was less predictable, adults' advantage over children decreased possibly as a result of the need for them to employ suppression processes that was stronger than children's. Indeed, Bub *et al.* (2006) found some evidence that it may be children who exhibit the stronger suppression processes (see later on findings from our analyses of interference and facilitation according to overall speed of responding).

In line with our interpretation thus far, for RT, children's times increased much more steeply from congruent condition to incongruent condition on the unmixed task than the mixed task, whereas any increase by condition was similar for adults on both tasks. An even more stark interaction profile was observed for errors. Here, children's errors increased from congruent condition to incongruent condition more so on the unmixed task than on the mixed task, whereas for adults' the increase occurred more on the mixed task. This profile again suggests that children found it more difficult when they had to remain focussed in order to face trial after trial of the same neutral or the same incongruent stimuli (suggesting that, in some sense, all words were distracting regardless of their semantic links to the hue dimension – Lorsbach & Reimer, 2011).

Even in the congruent condition of the unmixed task, in responding near their maximum speed, when children occasionally noticed a word, they may sometimes have registered that they had done something other than what the task instructions required, and this tended to briefly put them off their task of hue naming, despite stimulus word and stimulus hue being in agreement (Szucs & Soltesz, 2010; Wright & Wanley, 2003). This difficulty maintaining the task set led to errors (e.g., stuttering, saying 'err' – responses likely to be excluded in our analyses), although not slowing them down for those responses that we designated unerroneous and which were therefore included in our analyses (Rand *et al.*, 1963). This contrasts with the mixed task, where, throughout the task, children slowed their responses because of having to switch between Stroop conditions within any given block, and this had the effect of reducing attentional slips and hence we observed lower errors (Eidels, 2012). Thus, one of children's problems might be one of proactive control, in so far as compared with adults, they find setting up, maintaining, and recovering from errors in their responses, rather challenging.

Effects of interference and facilitation

Subtracting neutral from incongruent condition to yield interference should remove factors common to both these conditions, such as general slowing, delays whilst initially perceiving the stimuli, initiating the verbal response, etc. (Hanauer & Books, 2005; Henik, 1996). On this conception, any differences in RT or errors between neutral and incongruent conditions should now reflect the psychological manifestation of the difference in semantic relationship between the neutral condition and the incongruent condition. Although semantic differences might build up if we compare a list format with a trial-by-trial format (Kindt *et al.*, 1997; Penner *et al.*, 2012), our own findings suggest that interference RTs might be identical as long as the two tasks are similar in construction and response format (van Mourik, Oosterlaan, & Sergeant, 2005).

Our finding that interference RT did not vary between children and adults suggests that the semantic structure of the basic colour space and its proximity (in terms of mental space) to our neutral words is stable by 9–11 years and does not alter into adulthood (Wright & Wanley, 2003). This held for our unmixed task versus mixed task. However, for interference errors, children now showed a much more pronounced effect than did adults and made more errors on the unmixed task compared with adults who made more errors on the mixed task. This suggests that errors do not always reveal the same trends as found for RT. But additionally, it is in line with our earlier interpretation that children find maintaining a task set regarding the incongruent condition compared with the neutral condition, far harder than do adults, with adults finding randomly moving between three conditions within a block harder compared with children.

Turning to facilitation, MacLeod and MacDonald (2000) supported their inadvertent-reading hypothesis with various studies. In one study, bilingual participants always responded to the hue in their second language. Now, the interference effect was unaffected but facilitation was much reduced. This suggested facilitation derives from a different source to interference. In line with predictions we derived from MacLeod and MacDonald's theory, our unmixed task led to higher facilitation RT than our mixed task and likewise for facilitation errors. Our account is that in an unmixed task congruent condition, any loss of focus leads to useful raised semantic activation or a useful prepared response regarding the colour to be reported (recall word and hue require the same colour-name – Brown *et al.*, 2002; Pratte *et al.*, 2010). As inadvertently reading the word instead of naming the hue in the unmixed neutral condition carries no such benefit, facilitation is increased (Wright & Wanley, 2003). On the mixed task, congruent trials are interleaved between a greater total number of neutral and incongruent trials, and so the strategy for congruent trials should be abandoned in favour of a strategy based on suppressing all words. Hence, we found mixed task facilitation was less pronounced (Mead *et al.*, 2002).

Of relevance, Braet *et al.* (2011) contrasted a congruent condition and an incongruent condition on an unmixed task, yielding an effect that, on our conception here, was actually a composite of facilitation + interference (see also Eidels, 2012; Ikeda *et al.*, 2013 for application of this index). Assuming the interference component was relatively stable (see above), their association will reflect mostly the facilitation component. Of note, Braet *et al.*'s (2011) index was found to increase with adults' reading skill. This is precisely what we would expect if Stroop effects such as facilitation result partly from reading issues (Faccioli *et al.*, 2008; Lorsbach & Reimer, 2011; Protopapas *et al.*, 2007; Wright, 2014). Thus, Braet *et al.*'s (2011) finding is in line with our present assertion that Stroop facilitation reflects the RT advantage gained by inadvertently reading the word dimension when trying only to respond to the hue dimension of the stimulus (MacLeod & MacDonald, 2000).

Concerning differences by Group, both in terms of RT and errors, children's facilitation was over twice the magnitude of adults' (Wright & Wanley, 2003). According to our adopted theory, this is because children are more prone to inadvertent word reading (e.g., attentional slips of focus) than are adults (Ikeda *et al.*, 2013; Imbrosciano & Berlach, 2005; Schwartz & Verhaeghen, 2008). Various other groups are also more prone to inadvertent word reading – for example, a subgroup of patients feigning extent of serious brain injury versus a subgroup of patients genuinely brain injured (Arentsen *et al.*, 2013). A key difference between such groups is the need for the non-genuine group to apply top-down strategic processing (or greater proactive control) in order to achieve their desired profile.

Although the inadvertent word-reading explanation is supported by some empirical evidence, this does not mean it is necessarily a complete explanation. In a competing account, Eidels (2012) argues that in the Stroop task, a double-target stimulus arises from the fact that in the congruent condition, word and hue would both require the same response. By contrast, the neutral and incongruent conditions are different instances of single-target stimuli, where the non-focal (i.e., redundant) stimulus dimension requires a different response than the target dimension (Townsend & Nozawa, 1995). Now, as children already process hues slower than adults (Comalli *et al.*, 1962), the word dimension can assist their congruent times disproportionately compared with neutral and incongruent conditions. It is this that leads to greater facilitation for children compared with adults.

Unfortunately, Eidels did not include a neutral condition in empirical validations of his computational model. But the difference between neutral and incongruent conditions cannot be put down simply to double-target versus single-target stimuli. Additionally, Eidels' theory does not predict that facilitation should alter depending on whether the same stimuli are presented in mixed blocks or unmixed blocks. Hence, that account, although clearly attractive, is currently insufficient for explaining developmental Stroop data.

Explaining facilitation and interference using overall speed of responding

There is another alternative account of our child versus adult differences in facilitation RT. Namely, children have slower overall responses and it may be this fact, rather than inadvertent word reading that causes their greater facilitation compared with adults (e.g., see Bub *et al.*, 2006 for just this finding regarding interference). An implication from this profile would be that children's facilitation qualitatively might be the same as adults', with any apparent group-wise difference in our above facilitation findings actually being due to response speed differences between the groups.

The indexes of interference and facilitation that we used should have reduced or eliminated general speed of responding, because the subtracting of one condition from another would cancel out general motor speed and anything else common to both conditions (Hanauer & Books, 2005; MacLeod, 1991; Posner & Snyder, 1975). Nevertheless, to consider this alternative account, we plotted the mean of each of four quartile categories of overall speed of responding against facilitation, doing so for each participant on his/her group and task (unmixed or mixed). For adults, this produced a concaved 'U'-shaped curve function for facilitation RT on both the unmixed and mixed tasks. Interestingly, concaved functions have been associated with greater response suppression (Bub *et al.*, 2006), irrespective of whether adults were succumbing to inadvertent word reading. When we approached this statistically by analysing facilitation according to which quartile the participant's overall speed of responding fell into instead of using the means of those quartiles, the finding for the unmixed task was shown to be reliable. However, for children, both the delta plot functions and the quartile analyses produced only unreliable facilitation RT results. Thus, not only does overall response speed fail to account for facilitation differences between children and adults, but our analyses actually suggest that children's facilitation is not qualitatively the same as adults'.

Although our general analyses for interference RTs suggested adults and children exhibit identical interference, doing so for both tasks, our delta plots and quartile analyses were not that straightforward. The delta plots for adults were convexed resembling an inverted 'U', for both the unmixed and the mixed tasks. For children, the functions were broadly linear on unmixed and mixed tasks. Then, in the statistical analyses, whereas adults did show a reliable increase in interference RT with overall speed of responding for the unmixed task only, children did so only for the mixed task. Thus, despite our earlier more global analyses for interference, there may in fact be qualitative differences between children and adults for interference RT after all (Arentsen *et al.*, 2013; Ehri & Wilce, 1979; MacLeod & MacDonald, 2000).

The above notwithstanding, suppression and task set maintenance effects are not necessarily exclusive of inadvertent reading. For instance, a participant (child or adult) who momentarily loses track of the task will have switched to word reading even if he or she does not realize the switch consciously. This would benefit the congruent condition but lead either to errors or to a slowed subsequent response to the target dimension, as the participant recovers. Similarly, suppression already features as part of the inadvertent word-reading hypothesis, directly lying particularly behind incongruity and interference effects. Although they may be related, it should nevertheless be possible to tease suppression and response set maintenance apart from inadvertent reading in a future study. However, what is clear from the present study is that if we wish to obtain more fine-grained delta plot analyses of child data (e.g., means of around 8 Octile categories – Pratte *et al.*, 2010; Soutschek *et al.*, 2013), developmental studies may require even larger child samples than in the present study.

Conclusions

From our above discussions, two conclusions follow. First, in investigating group differences, facilitation may be even more informative an effect than is interference. However, if we want to reduce the role of inadvertent word reading in Stroop facilitation, we should rely more on mixed tasks than unmixed tasks. This is because mixed tasks reduce the likelihood that a successful inadvertent-reading strategy on the present trial will be successful on the next trial.

However, a second conclusion is that, just because they offer participants a shortcut in the congruent condition, unmixed tasks are not to be considered of no utility: Indeed, the interaction between unmixed and mixed tasks here for children versus adults raises the possibility that comparing facilitation in typically developed groups versus in atypical groups (e.g., having ADHD, depression, Schizophrenia anxiety, dyslexia, or learning impairments) might also show up dynamic changes in mixed versus unmixed tasks which can help discriminate among clinical and non-clinical groups, or otherwise tell us more about how attention works or is compromised than we could readily discern from only one task on its own (Arentsen *et al.*, 2013; Faccioli *et al.*, 2008; Helland & Asbjørnsen, 2000; Imbrosciano & Berlach, 2005; Kindt *et al.*, 1997; Schoot *et al.*, 2000; Schwartz & Verhaeghen, 2008; van Mourik *et al.*, 2005; Wright, 2014; Wright, Peters, *et al.*, 2015). For instance, the inadvertent word-reading hypothesis used together with a mixed task and unmixed task with participants having dyslexia can be used to determine whether processing the word dimension is obligatory or under conscious control (these make different predictions about the congruent RTs and errors on the respective congruent conditions).

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