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Two studies investigated whether the greater Stroop interference reported in children with reading difficulties compared to typical readers of the same age represents a generalized deficit in interference control or a consequence of their reading problems. In Study 1, a color-word Stroop task and a nonverbal task involving responses to locations associated with pictures were administered to 23 children with single word reading difficulties and 22 typically developing children matched for age and nonverbal ability. Children with reading difficulties showed disproportionate interference effects in the color-word Stroop but not the nonverbal task. In Study 2, groups of poor and typical readers completed a spatial Stroop task with printed input that did not require a verbal response and a nonverbal analogue. Both groups showed comparable interference in these two tasks. Thus, the reported problems in the color-word Stroop task in children with reading difficulties do not appear to entail general impairments in interference control.

Keywords: Reading difficulties; Stroop effect; Inhibitory control; Interference; Phonological skills.

Whilst difficulties in reading single words accurately and fluently in childhood are widely believed to have their origins in phonological processing deficits (e.g., Shaywitz & Shaywitz, 2005; Vellutino, Fletcher, Snowling, & Scanlon, 2004), there have also been reports of impaired abilities to inhibit dominant responses in order to execute controlled actions (Everatt, Warner, Miles, & Thomson, 1997; Helland & Asbjørnsen, 2000; Kapoula et al., 2010; Kelly, Best, & Kirk, 1989; Reiter, Tucha, & Lange, 2005; van der Schoot, Licht, Horsley, & Sergeant, 2000). These findings are based largely on the Stroop task, which involves naming the ink color whilst ignoring the conflicting color names of the words. It is unclear whether the increased interference observed in this population is a
consequence of general impairments in their abilities to suppress goal-irrelevant responses or of more deficits in the phonological, word recognition, or naming skills tapped by this paradigm. The aim of the present study was to investigate whether high levels of interference in children with reading difficulties are restricted to specific elements of this paradigm such as the presence of conflicting print stimuli and naming responses or extend more generally across tasks requiring the control of both verbal and nonverbal interference.

In the Stroop task, the primary stimuli are color words printed in incongruent ink colors (e.g., the word red printed in blue ink), and the task is to name the ink color. Performance is impaired in this incongruent condition compared with a neutral condition in which the word is not a color, or with the congruent case where the word and its color match. It is widely assumed that despite instructions to ignore the color word, it is processed rapidly and automatically, generating a conflicting response (MacLeod, 1991; MacLeod & MacDonald, 2000). On these grounds, it might be expected that children with word decoding difficulties will show a diminished interference effect, as their speed of recognizing the incongruent color word should be slowed. Indeed, in the extreme case of individuals who cannot recognize the printed word forms, no interference at all would be expected in the incongruent condition.

Contrary to this prediction, individuals with reading difficulties have been consistently found to show greater interference than typical readers (Everatt et al., 1997; Faccioli, Peru, Rubini, & Tassinari, 2008; Helland & Asbjørnsen, 2000; Kapoula et al., 2010; Kelly et al., 1989; Protopapas, Archonti, & Skaloumbakas, 2007; Reiter et al., 2005). van der Schoot et al. (2000) compared children with the guessing subtype of dyslexia (fast but inaccurate) with children with the spelling subtype (accurate but slow) in the stop signal task and the Stroop task. Guessers were impaired in their ability to inhibit inappropriate responding on these tasks, leading to the speculation that the specific reading disorder of guessers may be associated with the same inhibitory deficits that underlie attention deficit/hyperactivity disorder (ADHD). In line with this, Reiter et al. attributed the increased Stroop interference in their poor readers to difficulties in inhibiting a competing response (see also Helland & Asbjørnsen, 2000; Kapoula et al., 2010; Kelly et al., 1989).

Others have argued that increased interference may be related to reading ability more directly. In a typically developing sample of children, Protopapas et al. (2007) found that poorer reading skills were correlated with greater Stroop interference. These authors suggested that in the color-word Stroop task, correct responses (ink color naming) are possible only after inappropriate responses (word reading) are blocked. By this account, slower word reading speed leads to delayed word recognition and hence to later selection of the color naming response in the incongruent condition. Consistent with this view, Everatt et al. (1997) reported Stroop effects of equivalent magnitudes in children with reading difficulties and younger reading-level-matched children.

It is therefore unclear as yet whether the greater Stroop interference reported in children with reading difficulties compared to typical readers of the same age represents deficits in executive control related to inhibition of goal-irrelevant but dominant responses or is caused by their reading problems. Addressing this issue requires the use of other Stroop-like paradigms that do not involve printed words. In one relevant study, van der Sluis, de Jong, and van der Leij (2004) compared Dutch-speaking children with reading difficulties, characterized by slow word reading speed, with age-matched typical readers in naming and inhibitory tasks involving objects, digits, and quantities. In the quantity
inhibition task, arrays of digits were presented, and participants were asked to count the number of digits in arrays containing incongruent digits (e.g., 222). In the object inhibition task, the child attempted to name a small object that is placed inside a larger one. There was little evidence in this study for a generalized deficit in the control of interference: Although children with reading difficulties were slower in naming digits and letters, they were not differentially impaired when naming speed was taken into account.

Here we report findings from two studies investigating interference control in children with reading difficulties in verbal and nonverbal tasks. In Study 1, a group of children with reading difficulties and a comparison group of typical readers completed a color-word Stroop task and a nonverbal task with similar task demands, the Pictures test (Davidson, Amso, Anderson, & Diamond, 2006). In this task, participants respond to a color picture of an apple or a sun with an associated right or left key press. The picture appears either on the side that is compatible or incompatible to its assigned key. Findings that children with reading difficulties are differentially disrupted by the incongruent condition in the color-word Stroop task but not the Pictures task would point to a specific difficulty in controlling interference from these verbal stimuli. Increased interference in this group in both tasks, on the other hand, would be consistent with a more general decrement in interference control.

STUDY 1

Method

Participants. A total of 316 children aged 8–10 years attending state primary schools in urban areas of the NE and SW of England participated in the screening phase of the study. The participating schools on average had 24.0% of pupils eligible for free school meals (an index of poverty in England), and 18.9% of pupils with special educational needs (without statements). These compare to the values of 18.5% and 18.2% for free school meals and special educational needs respectively for primary schools across England in 2010 (Clarke, 2010). All children completed the subtest of single word reading of the Wechsler Objective Reading Dimension (WORD; Wechsler, 1993) and the matrix reasoning subtest of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999). The matrix reasoning provides an index of nonverbal reasoning ability. The single word reading test of the WORD provided a measure of the children’s ability to read single words in isolation. Children were presented with a list of progressively more difficult words, and the test stopped when a child made four consecutive mistakes. The total number of words correctly read for each child was converted into a standard score.

The selection criteria for the reading difficulties group were a standard score of 85 or below on the single word reading test of the WORD (i.e., < = 1 standard deviation below the population mean) and a minimum of t-score of 40 in matrix reasoning of the WASI (i.e., > = 1 standard deviation below the population mean). A total of 23 children (7 females) met these criteria and were selected for participation. A comparison group of 22 children (12 females) who were typical readers conforming to the following criteria—standard scores > = 95 on the single word reading test and t-scores > = 40 in matrix reasoning were recruited. These recruitment criteria correspond to those employed in previous research on children with reading difficulties (e.g., Gooch, Snowling, & Hulme,
The proportion of children satisfying the criteria for reading difficulties in this screening sample was 7.3%, in line with levels of incidence in a population study reported by Yule, Rutter, Berger, and Thompson (1974). Children with reading difficulties and typical readers were matched individually within schools for their chronological ages (within 3 months) and standard matrix reasoning scores as closely as possible (within four points). Children with reading difficulties ($M = 80.39$, $SD = 5.02$) performed significantly more poorly than the typical readers ($M = 108.18$, $SD = 5.32$) on the word measure ($p < .001$), but the groups did not differ either in age (children with reading difficulties: $M = 116.95$ months, $SD = 6.06$ months; typical readers: $M = 114.54$ months, $SD = 7.82$ months, $p = .253$) or nonverbal ability (children with reading difficulties: $M = 47.30$, $SD = 4.72$; typical readers: $M = 47.00$, $SD = 4.35$, $p = .824$). Teachers confirmed the absence of any known comorbidities (e.g., speech sound disorder, specific language impairment, and ADHD) in children with reading difficulties and of significant educational problems in the group of typical readers. All children had English as a first language. Ethical approval for this study was granted by the University of York, Department of Psychology, Ethics Committee. Informed parental consent was obtained and completed prior to participating.

**Procedure.** The color-word Stroop task and the Pictures test were individually administered to all selected children in a quiet room of the school. The presentation order of these two tasks was counterbalanced.

**Measures.** Three conditions from the color-word Stroop test from Delis-Kaplan Executive Function System (D-KEFS; Delis, Kaplan, & Kramer, 2001) were administered individually to each child. In each condition, 50 stimuli were presented on a single page. In the color naming control condition, the child was shown a page on which are patches of color and are asked to name the colors as quickly as they can without skipping any or making mistakes. The three colors were green, red, and blue. In the word reading control condition, the child was asked to read color words printed in black shown on a page as quickly as they can without skipping any or making mistakes. The three color words were green, red, and blue. In the color naming incongruent condition, the child was shown color words printed in incongruent colors and was required to ignore the word and name the color of the ink that the words are printed in as quickly as they can without skipping any or making mistakes. Again, the three colors employed were green, red, and blue. Dependent variables were mean response times (RTs) per item and percentage of correct responses. The percentage of correct responses was calculated by dividing the number of correct responses by the sum of correct plus incorrect responses. Total time taken for each condition was recorded separately with a stopwatch. The child was allowed to make corrections. The time taken by the child to make corrections was included in their total RTs for the condition. Corrected responses were treated as incorrect responses. Interference effects were defined as difference between color naming incongruent and color naming control conditions.

On each trial of the Pictures test, a color picture of either an apple or a sun is presented on the left or right side of the computer screen. Each stimulus has an associated right or left response with a stimulus presentation time of 750 ms and an interstimulus time of 500 ms. Pictures of the two stimuli are displayed next to the correct buttons on the keyboard to minimize the memory load. The stimuli are presented randomly on the left or
right of the screen over the block of 33 trials, yielding 17 congruent trials (in which the stimulus appears on the same side as its associated response) and 16 incongruent trials (stimulus appears on the opposite side of its associated response). Inhibition is required on incongruent trials. Congruent trials are used as a control condition. The dependent variables are mean RTs and percentage of correct responses. A RT below 200 ms was considered anticipatory (Davidson et al., 2006) and was excluded from analyses. Mean RTs for correct responses were calculated for each child in each condition. The percentage of correct responses was calculated by dividing the number of correct responses by the sum of correct plus incorrect responses in each condition. Interference effects were calculated as the difference between incongruent and congruent conditions.

In both tests, means and standard deviations for the measures of RTs and accuracy were computed for each condition. Scores that were more than three standard deviations from the mean of the whole sample were identified as outliers and replaced by values at three standard deviations (Field, 2005).

Results

A two-factor analysis of variance (ANOVA) was conducted on RTs and percentage of correct responses for each of the color-word Stroop and the Pictures tasks, with group (reading difficulties, typical readers) as a between-subjects factor and condition (control, incongruent) as a within-subjects factor. RTs and percentage of correct responses for each task are displayed in Table 1.

For the color-word Stroop task, there was a significant main effect of group on the RTs, reflecting longer RTs of the children with reading difficulties in incongruent color naming, \(F(1, 43) = 5.31, MSE = 177480.91, \eta_p^2 = .11, p = .026\). The main effect of condition was also significant, \(F(1, 43) = 239.80, MSE = 79760.13, \eta_p^2 = .85, p < .001\), due to the fact that both groups showed the longer response times in the incongruent than the control color naming condition. There was a significant interaction between group and condition, \(F(1, 43) = 5.56, MSE = 79760.13, \eta_p^2 = .11, p = .023\), with children with reading difficulties showing a greater slowing of responses in the incongruent color naming condition than the typical readers. Given that the degree of interference is found to associate with word reading speed (Protopapas et al., 2007), color word reading speed was entered as a covariate in this two-factor ANOVA. The main effect of condition remained significant, \(p = .005\). However, there was no significant effect of group, \(p = .441\), nor was the interaction between group and condition, \(p = .061\). In addition, the Spearman’s rho revealed a significant correlation between the RT difference score (incongruent—control) and word reading speed, \(r = .32, p = .017\). Greater Stroop interference was associated with slower reading speed. Nonparametric statistics were employed due to non-normal distributed data, and nonlinear transformations may introduce unwanted distortions to the understanding of the nature of the relationship between Stroop interference and reading skills (see Protopapas et al., 2007).

A significant effect of group was also found in response accuracy, with the children with reading difficulties being more error prone than typical readers in incongruent color naming, \(F(1, 43) = 20.74, MSE = 12.42, \eta_p^2 = .33, p < .001\). The main effect of condition was significant, \(F(1, 43) = 74.09, MSE = 13.24, \eta_p^2 = .63, p < .001\). Both groups made more errors in the color naming incongruent condition than in the color naming control condition. There was also a significant interaction between group and condition, \(F(1, 43) = 13.19, MSE = 13.24, \eta_p^2 = .24, p = .001\),
with the children with reading difficulties showing a greater reduction in accuracy in incongruent color naming than the typical group.

On the Pictures task, the ANOVA conducted on the RT data yielded a significant effect of condition, $F(1, 43) = 39.33, MSE = 1746.34, \eta_p^2 = .48, p < .001$, due to longer RTs in the incongruent condition than in the control condition for both groups. However, there was no significant effect of group, $F(1, 43) < 1.0, MSE = 14254.79, \eta_p^2 = .00, p = .984$, nor was there a significant interaction between group and condition, $F(1, 43) < 1.0, MSE = 1746.34, \eta_p^2 = .01, p = .501$. The effect of condition on accuracy was significant, $F(1, 43) = 67.64, MSE = 59.97, \eta_p^2 = .61, p < .001$, due to reduced accuracy in the incongruent than the congruent conditions for both groups, and there was a significant effect of group, $F(1, 43) = 4.77, MSE = 97.90, \eta_p^2 = .10, p = .034$, reflecting the poorer performance of the children with reading difficulties. The interaction between group and condition was not significant, $F(1, 43) < 1.0, MSE = 59.97, \eta_p^2 = .02, p = .373$. Thus, in contrast to the color-word Stroop task, both groups showed comparable interference effects in the Pictures task.

In order to confirm this group-by-task domain interaction, a two-factor ANOVA was conducted with group (reading difficulties, typical readers) as a between-subjects factor and the RT difference score (incongruent—control) in each task domain (verbal, nonverbal) as a within-subjects factor. All three terms were significant: group, $F(1, 43) = 5.81, MSE = 82988.13, \eta_p^2 = .12, p = .020$, task domain, $F(1, 43) = 211.22, MSE = 80024.79, \eta_p^2 = .83, p < .001$, and the interaction between group and domain, $F(1, 43) = 5.08, MSE = 80024.79, \eta_p^2 = .11, p = .029$. The children with reading

### Table 1 Descriptive Statistics for the Principal Measures of Study 1.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Reading Difficulties $(n = 23)$</th>
<th>Typical Readers $(n = 22)$</th>
<th>$F$</th>
<th>$p$</th>
<th>$d$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Color-Word Stroop Task</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Word reading control</td>
<td>760 (178)</td>
<td>603 (122)</td>
<td>11.65</td>
<td>.001</td>
<td>1.02</td>
</tr>
<tr>
<td>Color naming control</td>
<td>946 (159)</td>
<td>882 (186)</td>
<td>1.55</td>
<td>.220</td>
<td>0.37</td>
</tr>
<tr>
<td>Color naming incongruent</td>
<td>2009 (534)</td>
<td>1664 (407)</td>
<td>5.89</td>
<td>.019</td>
<td>0.73</td>
</tr>
<tr>
<td>Difference</td>
<td>1062 (480)</td>
<td>781 (291)</td>
<td>5.56</td>
<td>.023</td>
<td>0.71</td>
</tr>
<tr>
<td>Percentage of correct response (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Word reading control</td>
<td>99.08 (1.46)</td>
<td>99.36 (1.14)</td>
<td>0.82</td>
<td>.371</td>
<td>0.27</td>
</tr>
<tr>
<td>Color naming control</td>
<td>97.13 (2.32)</td>
<td>97.73 (2.16)</td>
<td>0.79</td>
<td>.378</td>
<td>0.27</td>
</tr>
<tr>
<td>Color naming incongruent</td>
<td>87.74 (5.13)</td>
<td>93.91 (3.83)</td>
<td>20.77</td>
<td>.000</td>
<td>1.36</td>
</tr>
<tr>
<td>Difference</td>
<td>9.39 (5.86)</td>
<td>3.82 (4.27)</td>
<td>13.19</td>
<td>.001</td>
<td>1.09</td>
</tr>
<tr>
<td><strong>Pictures Test</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>611 (82)</td>
<td>617 (105)</td>
<td>0.04</td>
<td>.847</td>
<td>0.06</td>
</tr>
<tr>
<td>Incongruent</td>
<td>672 (66)</td>
<td>666 (98)</td>
<td>0.07</td>
<td>.797</td>
<td>0.08</td>
</tr>
<tr>
<td>Difference</td>
<td>61 (61)</td>
<td>49 (56)</td>
<td>0.46</td>
<td>.501</td>
<td>0.20</td>
</tr>
<tr>
<td>Percentage of correct response (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>91.56 (7.27)</td>
<td>94.64 (5.11)</td>
<td>2.69</td>
<td>.108</td>
<td>0.49</td>
</tr>
<tr>
<td>Incongruent</td>
<td>76.65 (12.09)</td>
<td>82.68 (9.42)</td>
<td>3.46</td>
<td>.070</td>
<td>0.56</td>
</tr>
<tr>
<td>Difference</td>
<td>14.90 (11.97)</td>
<td>11.96 (9.77)</td>
<td>0.81</td>
<td>.373</td>
<td>0.27</td>
</tr>
</tbody>
</table>

*Notes. Standard deviations are shown in parentheses. Differences in the color-word Stroop = color naming incongruent—color naming control (neutral). Differences in the Pictures test = incongruent—control (congruent).*
difficulties showed a greater interference effect in the color-word Stroop task. The corresponding ANOVA performed on accuracy scores revealed significant effects of group, $F(1, 43) = 5.18, \text{MSE} = 78.66, \eta_p^2 = .11, p = .028$, and task domain, $F(1, 43) = 15.46, \text{MSE} = 67.77, \eta_p^2 = .26, p < .001$, but a nonsignificant interaction between the two factors, $F(1, 43) < 1.0, \text{MSE} = 67.77, \eta_p^2 = .01, p = .453$.

Because the gender balance of the two groups differed, four separate ANOVAs were conducted with sex and group as independent variables and difference scores (RTs and accuracy) in each task as dependent variables. No significant main effects of gender or interaction between gender and group were found ($p > .05$ in all cases).

**Discussion**

Children with reading difficulties showed greater interference than typical readers with incongruent color word combinations in a Stroop task, but not in a corresponding nonverbal task that required matching of pictures with locations. These results suggest that reported problems in the Stroop color-word task in children with reading difficulties (see also Everatt et al., 1997; Helland & Asbjørnsen, 2000; Kapoula et al., 2010; Kelly et al., 1989; Protopapas et al., 2007; Reiter et al., 2005) may result from task-specific aspects of the Stroop paradigm rather than more generalized deficits in the attentional control of irrelevant information. In the Stroop task, children with reading difficulties were slow at reading a neutral color word than typical readers but performed at a comparable level to typical readers in terms of color naming of a neutral stimulus. The group difference in interference was eliminated after the speed of color word reading in the neutral condition was taken into account, suggesting that word reading ability was instrumental in the disproportionate amount of color-word Stroop interference in the poor readers. This aspect of present findings is consistent with Protopapas et al.’s results that greater Stroop interference is related to poorer reading skills. The slow rates of reading of children with reading difficulties therefore appear to have a direct impact on their disruption by conflicting word identity and ink color information.

The extent to which increased levels of interference in children with reading difficulties extends across tasks involving irrelevant printed verbal stimuli was explored in a further study. A key property of the color-word Stroop task is that the lexical forms of the irrelevant words correspond to the spoken responses to the ink color. This induces maximal lexical competition through phonological as well as categorical priming of the lexical items and this may induce full decoding or recognition of the print form, potentially generating interference. As this processing is a process in which the abilities of the children with reading difficulties and typical readers are clearly distinguished, it is likely to be the source of the increased Stroop interference demonstrated in Study 1.

In Study 2, we therefore investigated whether the increased levels of interference with verbal stimuli in children with reading difficulties persist when there is no requirement to produce a spoken response corresponding to the conflicting lexical identity of the printed text, thereby eliminating priming through phonological output. New samples of children with reading difficulties and typical reading abilities completed verbal and nonverbal interference tasks involving, in both cases, manual responses to the spatial location of congruent or incongruent stimuli. In the verbal task, the words “ABOVE” and “BELOW” were printed above or below a fixation cross, and participants were asked to respond to the spatial location (Palef & Olson, 1975). In the nonverbal task, arrows
pointing left or right were located either to the left or right of the screen, and the task was to respond on the basis of the arrow direction and to ignore the spatial location (Davidson et al., 2006).

The predictions were as follows. First, on the basis of the findings from Study 1 that children with reading difficulties do not show increased interference for conflicting nonverbal stimuli, group differences in the magnitude of interference effects were not expected for the nonverbal task. Second, if, as argued above, the increased level of interference of the children with reading difficulties in the Stroop tasks arises from the high levels of phonological priming of the color word responses inducing full processing of the potentially conflicting lexical stimuli, group differences would not be expected in the verbal task either, as this requires only a manual response to spatial location that does not require phonological output. Finally, if children with reading difficulties are impaired in controlling interference from any irrelevant verbal stimuli regardless of the requirement to make a verbal response, they should show increased levels of interference in the verbal task as they did in the color-word Stroop in Study 1.

STUDY 2

Method

Participants. A total of 373 children aged 8–10 years attending state primary schools in urban areas of the NE and SW of England participated in the screening phase of the study. The participating schools on average had 23.5% of pupils eligible for free school meals (an index of poverty in England), and 21.8% of pupils with special educational needs (without statements). These compare to the values of 18.5% and 18.2% for free school meals and special educational needs, respectively, for primary schools across England in 2010 (Clarke, 2010). The selection criteria were the same as those employed in Study 1, yielding 23 children with reading difficulties (10 females) and 23 typical readers (12 females). Children with reading difficulties (M = 79.04, SD = 5.24) obtained significantly lower reading scores (p < .001) than typical readers (M = 101.44, SD = 5.66). Groups did not differ in age (children with reading difficulties: M = 110.57 months, SD = 6.66 months; typical readers: M = 111.39 months, SD = 8.94 months, p = .724) or nonverbal ability (children with reading difficulties: M = 50.61, SD = 6.80; normal readers: M = 51.17, SD = 5.44, p = .757). The proportion of children satisfying the criteria for reading difficulties in this screening sample was 6.2%, in line with levels of incidence in a population study reported by Yule et al. (1974). Teachers confirmed the absence of any known comorbidities (e.g., speech sound disorder, specific language impairment, and ADHD) in children with reading difficulties and of significant educational problems in the group of typical readers. All children were native English speakers. Ethical clearance for this study was granted by the University of York, Department of Psychology, Ethics Committee. Informed parental consent was obtained and completed prior to participating.

Procedure. The tasks were individually administered to selected children. The presentation order of the verbal and nonverbal spatial Stroop tasks was counterbalanced across participants.
Measures

**Verbal Spatial Stroop task.** The task used by Palef and Olson (1975) was modified for the purposes of this study. The stimuli were the words “ABOVE” and “BELOW.” In the incongruent condition, the word “ABOVE” appeared below a central fixation in the screen, and the word “BELOW” appeared above the central fixation. These two words occurred equally often and in random order. The child was required to ignore the meaning of the word and to respond to its spatial location by pressing one of two response keys, labelled “above” and “below.” The ability to suppress goal-inappropriate responses is required in this condition. The control condition was the presentation of a yellow star in one of these two locations. The child needed to respond to the location of the yellow star. All children were tested in the control condition and then incongruent condition. In each condition, stimuli stayed on the screen until the child made a response. The interstimulus time was 500 ms. There were 20 trials in each condition with a practice block of 10 trials preceding experimental blocks. Instructions emphasized both the speed and accuracy of responses.

**Nonverbal Spatial Stroop task.** The task developed by Davidson et al. (2006) was modified for the purpose of this study. The stimuli were a single arrow pointing toward the right and left at a 45 degree angle. In an incongruent condition, the right-pointing arrow appeared on the left side of the screen, and the left-pointing arrow on the right. These two types of arrows occurred equally often and in random order. The child was instructed to press the key that the arrow was pointing to and to ignore the location the arrow appeared on the screen. The control condition was the presentation of the right-pointing or left-pointing arrow in a neutral spatial location, which is the center of the screen. The child had to press the key to which the arrow was pointing to. All children were tested in the control condition and then incongruent condition. The test procedure was identical to that used in the verbal spatial Stroop task.

Results

Two-factor ANOVAs were employed on RTs and percentage of correct responses for the two tasks with group (reading difficulties, typical readers) as a between-subjects factor and condition (control, incongruent) as a within-subjects factor. RTs and percentage of correct responses for each task are displayed in Table 2.

In the verbal spatial Stroop task, there was a significant main effect of condition on RTs, $F(1, 44) = 10.62, MSE = 40413.35, \eta_p^2 = .19, p = .002$, due to the slower responses in the incongruent than the control condition for both groups. Nonsignificant effects were found of group, $F(1, 44) = 1.71, MSE = 131521.47, \eta_p^2 = .04, p = .198$, and of the interaction between condition and group, $F(1, 44) = 0.18, MSE = 40413.35, \eta_p^2 = .00, p = .672$. Percentage of correct responses showed a significant effect of condition, $F(1, 44) = 6.03, MSE = 164.77, \eta_p^2 = .12, p = .018$, reflecting lower accuracy in the incongruent condition than in the control condition. There was no significant effect of group, $F(1, 44) = 0.01, MSE = 230.41, \eta_p^2 = .00, p = .933$, nor the interaction between condition and group, $F(1, 44) = 0.63, MSE = 164.77, \eta_p^2 = .01, p = .432$.

In the nonverbal spatial Stroop task, there was a significant main effect of condition on RTs, $F(1, 44) = 70.38, MSE = 15280.25, \eta_p^2 = .61, p < .001$, due to the longer RTs in the incongruent condition than in the control condition. There was also a significant effect
of group, $F(1, 44) = 7.64, MSE = 40501.71, \eta^2_p = .15, p = .008$, reflecting the slower responses of the children with reading difficulties. However, there was no significant interaction between condition and group, $F(1, 44) = 0.54, MSE = 15280.25, \eta^2_p = .01, p = .466$. None of the terms in the corresponding ANOVA performed on the accuracy data were significant: condition, $F(1, 44) = 3.67, MSE = 51.72, \eta^2_p = .08, p = .062$; group, $F(1, 44) = 3.32, MSE = 125.98, \eta^2_p = .07, p = .075$; interaction between condition and group, $F(1, 44) = 0.19, MSE = 51.72, \eta^2_p = .00, p = .664$.

**Discussion**

Study 2 tested the hypothesis that the use of the print form of words may conflict with spoken naming the ink color of the text and that this is the source of the increased Stroop interference in children with reading difficulties. In the new verbal interference task, the lexical content of the stimulus (above/below) was potentially incompatible with a manual response to the location of the text on the screen. An equivalent spatial location judgment task using nonverbal stimuli (arrows) was also tested. In both tasks, children responded more slowly to incongruent than neutral stimuli, and the magnitude of the interference effect was comparable across the two reading ability groups. The results suggest that problems in the color-word Stroop task in children with reading difficulties demonstrated in Study 1 are a consequence of task-specific aspects of the color-word Stroop paradigm, possibly relating to conflicts with the spoken response requirements that do not extend to tasks involving spatial judgments and manual responses.

Table 2: Descriptive Statistics for the Principal Measures of Study 2.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Reading Difficulties ($n = 23$)</th>
<th>Typical Readers ($n = 23$)</th>
<th>$F$</th>
<th>$p$</th>
<th>$d$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Verbal Spatial Stroop</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTs (ms) Control</td>
<td>653 (216)</td>
<td>572 (122)</td>
<td>2.44</td>
<td>.130</td>
<td>0.46</td>
</tr>
<tr>
<td>Incongruent</td>
<td>808 (432)</td>
<td>691 (308)</td>
<td>1.11</td>
<td>.297</td>
<td>0.31</td>
</tr>
<tr>
<td>Difference</td>
<td>154 (326)</td>
<td>118 (235)</td>
<td>0.18</td>
<td>.672</td>
<td>0.13</td>
</tr>
<tr>
<td>Percentage of correct response (%) Control</td>
<td>93.91 (6.21)</td>
<td>96.30 (5.68)</td>
<td>1.86</td>
<td>.180</td>
<td>0.40</td>
</tr>
<tr>
<td>Incongruent</td>
<td>89.46 (17.95)</td>
<td>87.61 (19.94)</td>
<td>0.11</td>
<td>.742</td>
<td>0.10</td>
</tr>
<tr>
<td>Difference</td>
<td>4.45 (17.17)</td>
<td>8.70 (19.08)</td>
<td>0.63</td>
<td>.432</td>
<td>0.23</td>
</tr>
<tr>
<td><strong>Nonverbal Spatial Stroop</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTs (ms) Control</td>
<td>555 (131)</td>
<td>458 (88)</td>
<td>8.60</td>
<td>.005</td>
<td>0.86</td>
</tr>
<tr>
<td>Incongruent</td>
<td>790 (249)</td>
<td>655 (155)</td>
<td>4.85</td>
<td>.033</td>
<td>0.65</td>
</tr>
<tr>
<td>Difference</td>
<td>235 (207)</td>
<td>197 (134)</td>
<td>0.54</td>
<td>.466</td>
<td>0.22</td>
</tr>
<tr>
<td>Percentage of correct response (%) Control</td>
<td>91.18 (8.38)</td>
<td>94.78 (5.74)</td>
<td>2.91</td>
<td>.095</td>
<td>0.50</td>
</tr>
<tr>
<td>Incongruent</td>
<td>87.64 (13.89)</td>
<td>92.57 (7.72)</td>
<td>2.21</td>
<td>.144</td>
<td>0.44</td>
</tr>
<tr>
<td>Difference</td>
<td>3.53 (12.29)</td>
<td>2.22 (7.47)</td>
<td>0.19</td>
<td>.664</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Notes. Standard deviations are shown in parentheses. Difference in all tests = incongruent–control (neutral).
GENERAL DISCUSSION

Children with reading difficulties showed disproportionately great interference in the color-word Stroop test in Study 1 than typically developing children of the same age. However, these problems did not extend to other verbal or nonverbal interference paradigms. In Study 1, children with reading difficulties showed equivalent levels of interference effects with incongruent nonverbal stimuli in a task that required matching objects with locations. Study 2 compared the performance of children with reading difficulties and age-matched typical readers on two spatial interference tasks (one involving verbal stimuli and one nonverbal) requiring manual responses to the spatial locations of the stimuli. Although response times were substantially slowed in the incongruent conditions in both tasks, the disruption was equivalent for both reading ability groups.

This restriction of the increased sensitivity to interference in children with reading difficulties to the classic color-word Stroop paradigm rules out an explanation in terms of domain-general impairments in the inhibition of inappropriate responses (e.g., Kelly et al., 1989). The current finding is consistent with a recent study where a different approach was taken and showed that children with specific reading decoding problems do not appear to have problems in controlling interfering information while performing working memory tasks when compared to groups of children known to have poor comprehension or ADHD (Palladino & Ferrari, 2013). These authors argue that, while poor comprehenders who are known to be less efficient to control for interfering information in passage reading (Cain, 2006; Gernsbacher, Robertson, Palladino, & Werner, 2004; Pimperton & Nation, 2010), poor decoders’ difficulties is more related to their problems in phonological information processing.

The key issue now is why the color-word Stroop task alone induces disproportionate interference in this population. There are several possibilities. First, it is generally assumed that word recognition is a highly automatic process and, consequently, that individuals have to suppress the tendency to read the word in order to correctly name the ink color (Cohen, Dunbar, & McClelland, 1990). In our study, interference effects were found to be statistically equivalent in poor readers to typically developing children in the color-word Stroop task when color word reading speed was taken into account, which is consistent with Protopapas et al.’s (2007) report that greater Stroop interference is related to poorer reading skills. Based on a model proposed by Roelofs (2003), Protopapas et al. proposed that this was due to a blocking mechanism that prevents automatic reading responses from being produced. By this account, lower word reading speed will lead to later activation of this mechanism, causing a delay in correct color naming in the incongruent condition.

Why, then, did the increased susceptibility to interference in the children with reading difficulties not extend to the verbal task in Study 2, which employed orthographic stimuli associated with conflicting responses in the incongruent conditions? In this task, the stimuli were the words above and below and the task was to respond with a key press to the location of the text on the screen and not to its meaning. Hence, although printed text is used, the phonological form of the lexical content is not highly primed and does not need to be retrieved in order to make the manual response to spatial location. As a consequence, response competition would not arise in response to the incongruent condition and there would be no delay in the activation of the blocking mechanism and, hence, of the selection of location. Note though that in both groups responses were slowed to incongruent verbal stimuli, indicating that the lexical content of the words was
accessed. This suggests that children with reading difficulties have intact abilities to retrieve meaning from print, although their phonological retrieval is impaired (Ramus & Szenkovits, 2008; Snowling, van Wagtendonk, & Stafford, 1988; Swan & Goswami, 1997). Thus, as long as retrieval of the phonological form is not attempted or required by the broader task context, interference effects would be expected to be comparable with those of typical readers.

A further explanation for the differences in interference is variability in task sensitivity to response competition. Stroop interference may be particularly potent as a consequence of its combination of high-frequency distractor words with the relatively unusual task of naming ink color. This is likely to cause high levels of cognitive competition and hence make heavy demands on cognitive control. In contrast, the other verbal interference task involves the participants making arbitrary manual responses based on recently acquired associations, a process less likely to generate readily competing responses to the distractor dimensions due to the lower associative strengths. Perhaps, then, children with reading difficulties simply have relatively subtle deficits in the executive processes of cognitive control that manifest themselves in disproportionate interference only in activities that are maximally demanding of the processes required to override highly practiced responses to goal-irrelevant stimuli, such as the color-word Stroop test. These difficulties may themselves be the consequence of underlying phonological deficits (e.g., Vellutino et al., 2004) that require the children to divert general attentional resources when processing the phonological structure of language when, for example, preparing a spoken response.

One limitation of the current study design was that the color-word Stroop test was administered in sheet form. This makes it impossible to fully rule out the explanation that the increased color-word Stroop interference may be due to poor readers’ failure in executive planning and control of sequential processing that were required to go through the stimulus sheet. However, on the basis of findings from van der Sluis et al. (2004) that children with reading difficulties were not differentially impaired in the inhibitory tasks administered in sheet form, it seems unlikely that the greater color-word Stroop interference of the reading difficulties group reflects problems with executive control of sequential processing required in tasks given in sheet form. Consistently, in the current data, it is noted that children with reading difficulties had a comparable level of performance in the color naming condition that was also administered in sheet form. Additionally, the different strategy approaches used by both groups may be one possible source of observed group differences. This seems unlikely as it should have also impacted the children’s performance on the other interference tasks if this was the case. Nevertheless, the use of a single-item version of the task (i.e., one Stroop word displayed at a time) is suggested in future studies in that it can help minimize the need for focusing and systematic scanning processes. It can allow the random intermix of different trial types, potentially reducing the influence of set effects and minimizing the use of strategy (Davidson, Zacks, & Williams, 2003).

In summary, the present data establish that, although children with reading difficulties have some impairments in the cognitive control of responses to task-irrelevant stimuli in the color-word Stroop test, they cannot be readily explained in terms of a pervasive decrement in the control of interference (e.g., Kelly et al., 1989). We speculate that these impairments result from their slow word decoding or are manifest only under conditions when the demands on response competition are greatest for this population known to have phonological deficits, for example, when a speeded spoken response is required and when
the distractor dimension is highly salient and the competing response highly practiced. These speculations remain to be systematically investigated in future studies.

REFERENCES


