Word Reading Practice Reduces Stroop Interference in Children

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Abstract

Stroop interference is often explained by an automaticity account, according to which it arises due to more extensive practice in reading than in color naming. Here we investigated the effect on interference of isolated practice in color naming (of incongruent and neutral stimuli) and in word reading (of color names) in adults and children in Grades 4–5. In both groups interference was reduced after practicing color naming of incongruent stimuli. For children, interference was also reduced after practice in word reading of color names. In neither group was interference diminished after practice in color naming of neutral stimuli. These findings are consistent with a negative relationship between reading ability and interference and challenge the automaticity account.

Keywords: Stroop Interference; Reading; Color Naming; Training; Automaticity

Stroop Interference and Reading Ability

One of the most familiar, most studied and most cited phenomena in cognitive psychology is Stroop interference. It is a robust finding that it takes longer to name the color of the ink in which a word is printed when the stimulus is a word denoting a different color (e.g. the word "red" printed in green ink) than when the stimulus is a string of colored letters (e.g. XXX) or a plain rectangular patch. MacLeod (1991) reviewed the evidence for variants of this task and addressed three issues that are crucial for understanding the causes of the Stroop effect: practice, integration, and the relation between facilitation and interference.

For the purposes of our analysis the concepts of practice and automaticity are of major importance. The notion of automaticity has been central for understanding and explaining the Stroop effect, since it is generally considered obligatory to read the word but not to name the color. This imbalance is thought to arise from our extensive practice in reading but not in color naming. The automaticity account considers Stroop interference as a consequence of a better-practiced skill, namely reading, that dominates color naming without regard of attention (Logan, 1997; MacLeod, 1991). Cohen, Dunbar, and McClelland (1990) proposed a connectionist model whereby practice in a task such as reading strengthens its connections and allows it to interfere with other tasks that have weaker connections, like color naming. Practice is seen as influencing the relative level of automaticity of two dimensions, resulting in interference. From this point of view reading and color naming differ along a continuum of practice and the degree of interference in the Stroop task may reflect the degree of word reading automaticity (Logan, 1997; Samuels, 1999).

Consequently, the degree of interference is often taken as a marker of word reading automaticity. This has significant practical implications, taking into account that word reading automaticity is been considered a fundamental element of reading development and as an essential background for more complex processes like reading comprehension (Kuhn & Stahl, 2003; Wolf & Katzir-Cohen, 2001).

One prediction that derives from the automaticity account is that poorer and less skilled readers will exhibit less interference in the standard Stroop task than good readers as a result of less practiced and therefore less automatized reading. This prediction stands in contrast to empirically observed data. A number of studies have showed that poor readers produce robust interference (Alwitt, 1966; Everatt, Warner, & Miles, 1997; Helland & Asbjørnsen, 2000; Kelly, Best, & Kirk, 1989; van der Schoot, Licht, Jorsley, & Sergeant, 2000). Everatt et al. (1997) found that children with dyslexia exhibit more interference than age-matched controls. More recently, Protopapas, Archonti, and Skaloumbakas (2007) showed that reading ability is negatively related to Stroop interference. In a first study they compared children with dyslexia to age-matched controls in the Stroop task and reported greater interference for the children with dyslexia. In a second study they examined the relationship between interference and reading skills in the general school population and found that poorer reading skills were associated with more interference. Furthermore, interference was found to be primarily associated with reading speed. Protopapas et al. suggested that reading ability and interference are directly linked, without mediation from executive functions such as attention and inhibition.

In line with these observations, Faccioli et al. (2008) also found that 7- to 12-year-old Italian children with dyslexia exhibited larger interference than a control group. The same pattern of results was reported by Kapoula et al. (2010) for French teenagers with dyslexia. These findings run counter to the automaticity account and challenge the notion that interference can be used to assay word reading automaticity.

In place of automaticity, a blocking mechanism, as implemented in the computational model WEAVER++ (Roelofs, 2003), may account for the empirical findings. According to this model, word reading can directly activate lemma retrieval and word-form encoding, whereas color-naming must pass through conceptual identification before activating lemma retrieval and word-form encoding. Stroop interference is assumed to occur because color naming must wait until the incorrect response (from word reading) is suppressed. As a consequence of the basic assumptions of the model, greater reading speed leads to less Stroop interference, consistent with the data.

Training

Although the effects of practice on the Stroop task have been of concern since the very beginning, only a small number of studies have examined this relationship. Stroop (1935) himself tried to examine the development of interference through practice in color naming and found that interference can be present even after 8 days of practice.

MacLeod and Dunbar (1988) trained participants to respond to shapes with familiar color names. Prior to practice, "shape naming" suffered from interference from incompatible colors, an effect that was reversed 20 days later. After training, participants showed interference in naming the colors but not in naming the shapes.

Other studies have used mixed or incongruent-only stimuli and have succeeded to reduce but not eliminate interference (Davidson, Zacks, & Williams, 2003; Dulaney & Rogers, 1994; MacLeod, 1998). However, so far no study has examined the effects of practice on the individual task dimensions involved in Stroop interference, namely plain color word reading and color naming of neutral stimuli.

Rationale of the Present Study

In light of the aforementioned findings the aim of the present study was to examine how interference is affected by practice not only in color naming but also in word reading. According to the automaticity account, practice in color naming should make this otherwise unpracticed dimension more competitive and thereby decrease interference, while practice in word reading might strengthen an already practiced dimension and thereby further increase interference, at least when reading skill has not yet reached ceiling performance. However, if the relationship between reading ability and interference is negative, as proposed by Protopapas et al. (2007), practice in color naming should have little effect on interference, because the bottleneck causing interference does not involve the processing of color but the delay in rejecting the word.

In contrast, practice in word reading could lead to a reduction of interference insofar as there is any potential for increase in the speed of reading the color words.

Adults are skilled readers and are considered to have achieved a high level of word reading automaticity. Therefore training in word reading should not affect interference in this population. In contrast, word reading automaticity has only partially developed in children and can improve further through practice, leading us to the prediction of a reduction in Stroop interference through practice in word reading.

Method

Participants

The study included adults and children from the general school population. The adult sample comprised 92 volunteers 18–40 years old, including 25 in the incongruent color group, 23 in the neutral color group, 22 in the word group, and 22 in the control (no-training) group. The school sample consisted of 105 children attending Grades 4–5, including 22 in the incongruent color group, 26 in the neutral color group, 31 in the word group, and 26 in the control group.

Materials

The Greek words for red (κόκκινο /kocino/), green (πράσινο /prasino/), and yellow (κίτρινο /citrino/) were used, because they have the same number of letters and syllables, comparable written frequency, and begin with voiceless stops, which facilitate response time triggering. The corresponding colors are familiar and easily distinguishable. The color word condition included these three words in white font.

Stimuli for the neutral color condition were made up of 7 repetitions of the letter X (no spaces) in red, green, and yellow color (RGB #FF0000, #00FF00, and #FFFF00, respectively). For the incongruent condition the Greek words for red, green and yellow appeared in a non-matching color. All stimuli were presented on a black background.

Procedure

Testing. On Day 1 the first interference measurement was taken. Participants were asked to name the color of the ink as quickly as possible and to try to avoid errors. A blocked design was implemented to minimize errors. The neutral condition was administered first (24 stimuli, including 8 in each color), followed by the incongruent condition (24 stimuli, including 4 in each mismatching word-color combination). The number of test trials was determined in a pilot study, to minimize learning due to testing. Each stimulus appeared on the screen for up to 2 s. Responses were recorded via a headset under the control of DMDX (Foster & Foster, 2003). Four practice trials preceded data collection. The entire testing session lasted about 3 minutes. An identical measurement was made on Day 5, following practice.
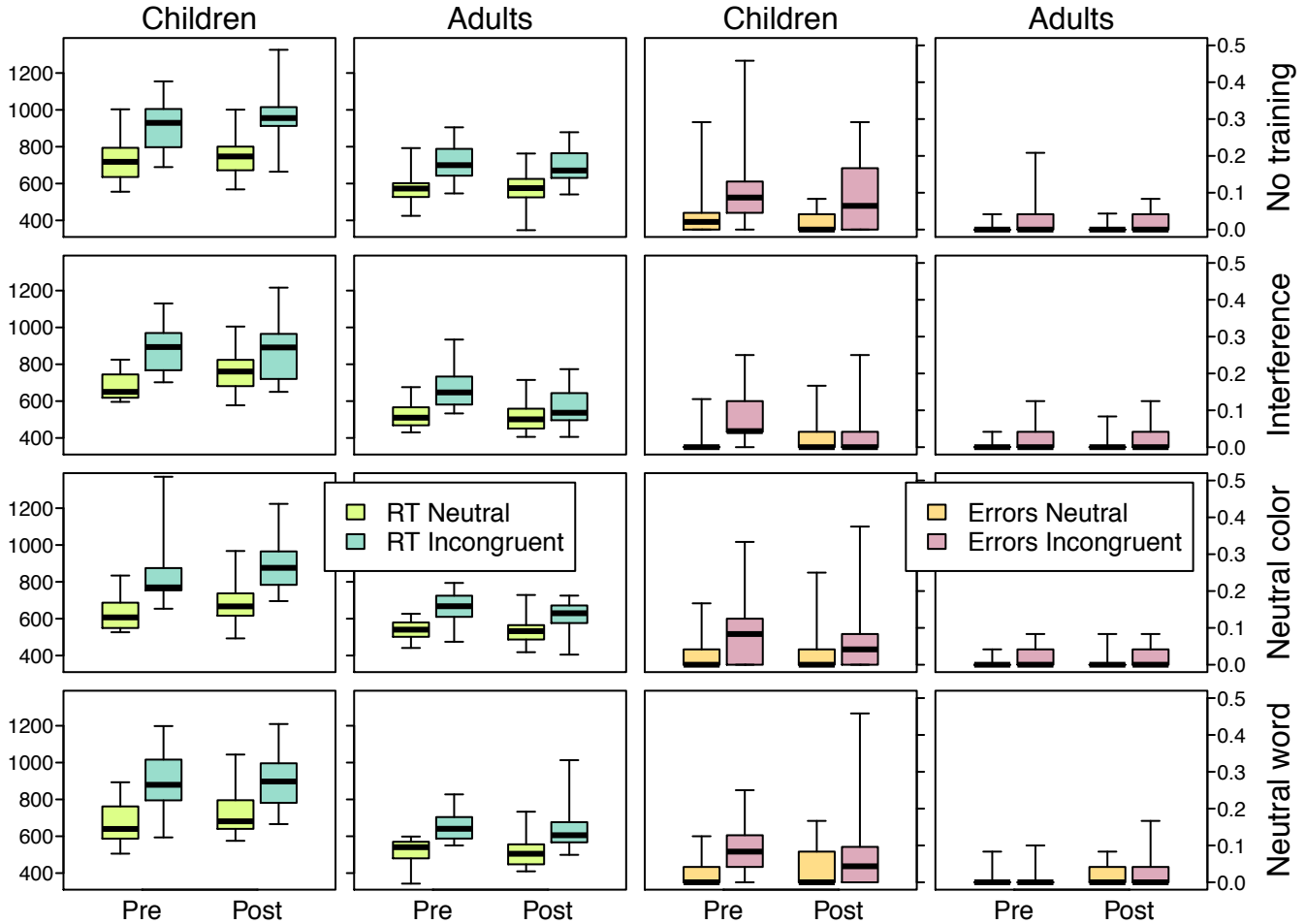
Figure 1 : Response times in milliseconds (left) and proportions of incorrect responses (right) for each sample (adults and children) in each condition (neutral and incongruent) and time point (pre- and post-practice). Each row of panels displays data for one experimental group (top to bottom: D, no practice; A, incongruent; B, color naming; C, reading). Each colored box contains the middle two quartiles of individual participant logarithmic means; the thick horizontal line marks the median; error bars extend to the full range.

Practice. Participants were assigned randomly into one of four conditions to practice for three consecutive days. Group A practiced color naming of incongruent stimuli (e.g. red), Group B color naming of neutral stimuli (e.g. XXXXXXX), and Group C practiced word reading of neutral stimuli (e.g. "red"). Children were required to complete one block of 144 trials per day. Adults completed one block of 192 trials per day. A fourth group (D) of control participants included no practice, to serve as a reference baseline.

Results

Responses were examined with CheckVocal (Protopapas, 2007) to determine accuracy and placement of the timing marks. Response times were subsequently logarithmically transformed to bring their distribution closer to normal.

To examine the differential effects of practice on interference between groups we tested a triple interaction between group, time, and condition using function lmer of

the lme4 package (Bates, Maechler, & Bolker, 2012) in R (R Core Team, 2012). Each training group was thus compared for effects of practice against the no-practice group. We employed linear mixed-effects models with maximal random structures (Barr, Levy, Scheepers, & Tily, 2013), that is, including random intercepts for participants as well as random slopes for time, condition, and their interaction. For response time, in R notation the model formula was specified as:

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logRT~time*cond*group+(time*cond|subject)
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Here, "time" refers to before vs. after practice and "cond" refers to neutral vs. incongruent (condition coding). Models were estimated with full maximum likelihood. The significance of the critical triple interaction was then tested via likelihood ratio test against a simpler model excluding the interaction from the fixed effects.

For children, as expected, the group practicing color naming in the incongruent condition significantly reduced

their time interference relative to the no-practice group ($\hat{\beta}$ = −.14, t = −3.83; χ^2 = 12.84, df = 1, p < .0005). The group practicing color naming in the neutral condition did not differ from the no-practice group ($\hat{\beta}$ = −.03, t = −.04; χ^2 = .49, df = 1, p = .482). In contrast, the group practicing color word reading significantly reduced their time interference ($\hat{\beta}$ = −.07, t = −2.05; χ^2 = 4.05, df = 1, p = .044).

For adults, the group practicing color naming in the incongruent condition significantly reduced their interference relative to the no-practice group ($\hat{\beta}$ = −.13, t = −3.44; χ^2 = 10.56, df = 1, p = .001). However, there was no significant change in interference either for the group practicing color naming in the neutral condition ($\hat{\beta}$ = −.03, t = −.83; χ^2 = .69, df = 1, p = .408) or for the group practicing word reading ($\hat{\beta}$ = −.02, t = −.45; χ^2 = .20, df = 1, p = .652).

To analyze error rates, we employed generalized linear mixed-effects models with binomial responses modeled via a logit link. Again, a maximal random structure was used.

For children, the group practicing color naming in the incongruent condition significantly reduced their accuracy interference relative to the no-practice group ($\hat{\beta}$ = −1.89, z = −2.34, p = .019). The group practicing color naming in the neutral condition did not differ from the no-practice group ($\hat{\beta}$ = −.43, z = −.68, p = .494), in contrast the group practicing color word reading significantly reduced their accuracy interference ($\hat{\beta}$ = 1.46, z = 2.04, p = .041).

For adults, there were no significant effects in the accuracy analyses (all p > .5).

Discussion

The results of the present study show that just three days of practice in word reading suffice to produce a reduction in Stroop interference in children. In contrast, interference did not diminish with practice in color naming of neutral stimuli in either population. Even though color naming is considered to be insufficiently automatized (indeed this is the usual explanation for the interference) and therefore presumably amenable to improvement through practice, this dimension of performance did not seem to have much effect on interference. In contrast, we found that interference can be reduced in children through practice in word reading of color names, a highly counterintuitive finding from the point of view of automaticity but a predicted outcome on the basis of the blocking hypothesis. It is strengthened by the fact that it was not replicated in adults, whose reading is skilled and presumably not amenable to improvement.

Our findings cannot be explained by the automaticity account. If Stroop interference derives from the imbalance between reading and color naming due to extensive practice in reading, then we should have observed the opposite pattern of results. Specifically, practice in color naming of neutral stimuli should strengthen the unpracticed dimension and thereby decrease interference, while practice in word reading should have made reading even more dominant and further increase interference. Both of these predictions were contradicted by the results.

Our main finding that word reading practice led to a reduction of Stroop interference is consistent with a negative relationship between reading ability and Stroop interference, as proposed by Protopapas et al. (2007). This relationship is due to the dependence of interference primarily on the speed of processing of the irrelevant stimulus, that is, of reading the word. The time needed to retrieve the irrelevant word response is a crucial factor in the process of interference because it sets a lower limit on the time taken to reject (inhibit) this response. Therefore the speed of reading puts severe constraints on interference. In contrast, neutral color naming may be related to incongruent color naming, because they are both color naming tasks (cf. di Filippo & Zoccolotti, 2012), but it is not specifically predictive of interference because there is ample time for the color naming response to build up while the inappropriate one (word reading) is retrieved and subsequently inhibited. This suggestion links word reading and neutral color naming, the two component tasks involved in Stroop interference, with the phenomenon of interference directly, via a blocking mechanism as proposed by Roelofs (2003).

Specifically, according to the computational model WEAVER++ (Roefols, 2003) a blocking mechanism prevents obligatory responses from being produced while allowing their processing speed to determine the non-dominant response latency. In this theoretical context, interference does not occur because of the relative processing strength of reading and color naming but because a fundamental architectural distinction forces color naming responses to wait until word reading responses are activated and then suppressed. This approach can explain our results in children, assuming that word lemma activation can benefit through reading practice by strengthening the direct connections between visual word stimuli and phonological word forms. This leads to a faster suppression of the word and ultimately to a faster color naming response.

Interference was also reduced in both groups with practice in color naming of incongruent stimuli. Presumably, in this condition participants learned to apply cognitive control more effectively and suppress the irrelevant response faster.

As our data were not constrained by any participant selection criteria and the participants were randomly assigned to the experimental conditions, there is no factor to attribute the differential development of interference other than the experimental manipulation, namely practice. Moreover, our implementation of an individual-item computerized version of the Stroop task, instead of the oft-employed sheet form, alleviates concerns related to task demands and spatial context that might impose consideration of attentional allocation factors (Lachter, Forster, & Ruthru, 2004; Risko, Stolz, & Besner, 2005). Without diminishing the significance of executive functions and attentional processes in interference, our data are consistent with the idea of a direct link between reading ability and Stroop interference.

One objection that may be raised against our interpretation is that three days of practice in color naming

of neutral stimuli may not have been enough to counterbalance years of experience in word reading in children, and especially in adults, so that a reduction of interference can be observed. However, if we take into account the effect of word reading practice in children, we see that three days of practice were enough to reduce interference despite years of previous experience with words. Thus it seems that a few hundred trials may be sufficient for these kinds of effects to emerge. Certainly, it cannot be precluded that additional factors modulate color and word processing and act differentially in the naming and reading tasks, but this is an issue beyond the scope of our current analysis, to be addressed in future study. However, from the point of view of a graded automaticity account, it still cannot be explained why practice in word reading did not increase Stroop interference but, instead, decreased it.

Close examination of the raw response times for children (Figure 1, left) reveals that post-training performance tended to be slower than pre-training performance, a trend visible also in the no-training group. This is an additional reason to use a control group rather than directly comparing pre- to post-training times. As it turned out, significant reduction of interference was associated with a lack of increase in post-training incongruent color naming times. So, in comparison with the control group, this amounts to faster responses.

To the best of our knowledge, this is the first training study of the simple skills involved in Stroop interference, namely reading and color naming, carried out with children. Therefore there is no closely related literature to compare our findings to. Because of the theoretical importance of these results and the implications for cognitive theories of conflict resolution processing, further research will be required to confirm and extend these findings to additional populations and tasks.

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