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Attention, Exposure Duration, and Gaze Shifting in Naming Performance

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Two experiments are reported in which the role of attribute exposure duration in naming performance was examined by tracking eye movements. Participants were presented with color-word Stroop stimuli and left- or right-pointing arrows on different sides of a computer screen. They named the color attribute and shifted their gaze to the arrow to manually indicate its direction. The color attribute (Experiment 1) or the complete color-word stimulus (Experiment 2) was removed from the screen 100 ms after stimulus onset. Compared with presentation until trial offset, removing the color attribute diminished Stroop interference, as well as facilitation effects in color naming latencies, whereas removing the complete stimulus diminished interference only. Attribute and stimulus removal reduced the latency of gaze shifting, which suggests decreased rather than increased attentional demand. These results provide evidence that limiting exposure duration contributes to attribute naming performance by diminishing the extent to which irrelevant attributes are processed, which reduces attentional demand.

Keywords: attention, exposure duration, eye movements, naming, Stroop

Attention in attribute naming performance has been studied extensively by using one of the most widely employed tasks in academic and applied psychology, the color-word Stroop task (Stroop, 1935). In a commonly used version of this task, participants name the color attribute of colored congruent or incongruent color words (e.g., the words GREEN or RED in green ink, respectively; say "green") or neutral series of Xs. Response time (RT) in Stroop task performance is longer in the incongruent than the neutral condition, descriptively called *interference*, and often shorter in the congruent than the neutral condition, descriptively called *facilitation* (for reviews, see Glaser & Glaser, 1989; MacLeod, 1991).

Since the beginning of experimental psychology, researchers have examined the influence of signal exposure duration on human performance (e.g., Wundt, 1900; see Woodworth, 1938, for a review of the early literature). More recent research has demonstrated that attribute exposure duration influences how quickly attributes are named in the Stroop task, as reflected in the mean RTs. When the color attribute of the color-word Stroop stimuli is removed (i.e., changed into neutral white color on a dark computer screen) 120 or 160 ms after stimulus presentation onset (e.g., RED in green ink is changed into RED in neutral white ink), the magnitude of Stroop interference is reduced compared with the standard continuous presentation of the color until trial offset (La Heij, van der Heijden, & Plooij, 2001). As argued by La Heij and colleagues (La Heij, Kaptein, Kalff, & de Lange, 1995; La Heij et al., 2001), the duration effect on Stroop interference is paradoxical: Whereas the only stimulus attribute present on the screen for most of the trial is an incongruent word, Stroop interference is less. The finding can be explained, however, if one assumes that removing the color attribute hampers the grouping of the color and word attributes into one perceptual object (i.e., a colored word) to which visual attention is allocated (cf. Kahneman & Henik, 1981; La Heij et al., 2001; Lamers & Roelofs, 2007; Roelofs & Lamers, 2007). Because the written color word receives less visual attention in the removed than in the continuous condition, the magnitude of the Stroop interference will also be less, as empirically observed. The utility of this account was demonstrated by computer simulations of the exposure duration effect using the WEAVER++ model of word planning and its attentional control (Roelofs & Lamers, 2007).

Lamers and Roelofs (2007) observed that Stroop interference is similarly reduced when color patches and words are used (instead of words in certain ink colors), and the color patch is removed 100 ms after stimulus onset. Moreover, they observed that if the color patch is not removed but only spatially repositioned (<2°) after 100 ms, Stroop interference is reduced too. The same reduction was obtained with repositioning the word while the color patch remained stationary. These results indicate a role for Gestalt grouping in attribute naming performance, as assessed by the color-word Stroop task. According to Gestalt psychology (Wertheimer, 1923), there are several principles by which attributes organize themselves in early perception. One of them is the principle of common fate, which holds that attributes that move simultaneously in the same direction with the same speed are grouped into a single perceptual object. If the grouping is hampered, as was the case with the color and word attributes in the experiments of Lamers and Roelofs (2007), the distractor word receives less visual attention than otherwise and the interference is reduced.

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In the experiments of Lamers and Roelofs (2007), perceptual grouping factors were manipulated while color-word presentation duration was kept constant. La Heij et al. (2001, Experiment 5) found some evidence that removing both color and word attributes shortly after stimulus presentation onset also reduced Stroop interference. This finding suggests that exposure duration per se plays a role too. Again, this finding can be explained by an attentional account (La Heij et al., 2001; Lamers & Roelofs, 2007; Roelofs & Lamers, 2007). If removing the whole color-word Stroop stimulus leads to an earlier disengagement of visual attention from that stimulus (including the word) than when the stimulus remains present throughout a trial, Stroop interference should be less, as observed. However, La Heij et al. (2001) argued that their finding concerning the effect of removal of the complete stimulus should be taken with some caution, because the reduced interference was not evident in a between-experiment comparison (i.e., their Experiments 1 and 2).

The available evidence suggests that exposure duration influences attribute naming performance by determining the extent to which irrelevant attributes are processed. If the effect of reduced exposure duration reflects decreased visual attention to irrelevant attributes, the effect on naming performance should result from shorter color naming RTs on incongruent Stroop trials at the short than long exposure duration. There should be no difference in RTs between neutral trials (i.e., Xs) in the short and long duration conditions. However, this pattern of results was not always obtained in the experiments of La Heij et al. (2001) and Lamers and Roelofs (2007). Rather, in some of the experiments, the reduced interference was obtained because RTs on neutral trials were longer at the short than the long exposure durations, whereas the RTs on incongruent trials did not differ between exposure durations. This suggests that removing the color attribute may make color naming more difficult and increase attentional demand. If the attentional demand is greater at the short than the long exposure duration, this would provide an alternative explanation of the reduced interference, as I explain next.

Following Helmholtz (see Pashler, 1998), several researchers have argued that irrelevant attributes are processed to the extent that target attribute processing requires attention (e.g., Kahneman, 1973; Lavie, 1995; Treisman, 1969). In support of this suggestion, previous research has demonstrated that distractor interference may be less if the perceptual demands of the task increase (e.g., Lavie, 1995, 2005). If color processing requires more attentional capacity at short than long exposure durations, less capacity might be available for distractor word processing and its interfering effect will be less (cf. Lachter, Ruthruff, Lien, & McCann, 2008). According to this alternative account, henceforth the attentional *capacity* hypothesis, color attribute removal increases the attentional demand of color naming, which decreases the extent to which distractor words are processed. In contrast, according to the account advanced by Lamers and Roelofs (2007; Roelofs & Lamers, 2007), henceforth the attentional *disengagement* hypothesis, color attribute removal causes attention to disengage earlier from the distractor words, which decreases the attentional demand of color naming.

Effects of perceptual load on selective attention have been demonstrated when targets and distractors are distinct objects that occupy separate spatial locations. However, in the classic Stroop task, color and word attributes are spatially integrated. Chen (2003) asked participants to identify colors by pressing corresponding keys. Perceptual processing load was manipulated by having participants decide whether to perform the color identification task on the basis of a single-feature perceptual cue in the low-load condition and a conjunction of features in the high-load condition. Manual RTs increased substantially from the low-load to the high-load condition. However, Stroop interference was greater when the load was high than when it was low. This suggests that higher perceptual load increases rather than decreases Stroop interference.

However, the findings of Chen (2003) do not rule out the attentional capacity account of the attribute removal effect observed by La Heij et al. (2001) and Lamers and Roelofs (2007). First, the standard Stroop task uses vocal rather than manual responding, so it is unclear whether the results on manual responding from Chen (2003) may be generalized to the vocal responding in the experiments of La Heij et al. (2001) and Lamers and Roelofs (2007). More important, the perceptual load manipulation in the study of Chen (2003) did not pertain to color processing directly, but concerned the processing of an unrelated perceptual stimulus that served as the basis for a go/no-go decision. It is unclear whether manipulating the demands of target color processing directly, as with removal of the color attribute, has the same effects as the perceptual load manipulation by Chen (2003). Finally, the temporal separation of color and word attributes achieved by removal of the color may be comparable with spatial separation. It has been observed that if target and distractor are spatially separated, distractor interference may be reduced by increasing perceptual load. To conclude, it remains possible that color removal reduces Stroop interference because the removal increases the attentional demand of color processing, which reduces the capacity available for word processing and thereby reduces its interfering effect.

Aims and Plan of the Present Study

I report two experiments that intended to examine the role of exposure duration in Stroop task performance and to assess the relative merits of the attentional capacity and disengagement accounts of the exposure duration effects. Attentional demand is not necessarily reflected in mean RTs. Therefore, the attentional demand of color naming at the short and long exposure durations was assessed by tracking the participants' eye movements. Although research on eye movements has a long history in experimental psychology (e.g., Woodworth, 1938) and predates the design of the Stroop task (Stroop, 1935), to my knowledge, eye movements have not been measured before during color-word Stroop task performance. Gaze shifting and the orienting of attention are tightly linked (see Wright & Ward, 2008, for a review). Past research showed that although individuals can shift the focus of attention without an eye movement (covert orienting), they cannot move their eyes to one spatial location while paying full attention to another location (i.e., shifts of eye position require shifts of attention). Thus, a gaze shift (overt orienting) indexes a shift of attention, preceded by attentional disengagement (Wright & Ward, 2008). Earlier research on picture and word naming performance has shown that gaze durations to pictures and words reflect at least partly the duration of central attentional engagement on planning the production of the vocal response (Meyer, Roelofs, & Levelt, 2003; Roelofs, 2007, 2008b, 2008c, 2008d). In a review of the literature, Griffin (2004) stated that "the production processes that appear to be resource demanding, based on dual-task performance, pupil dilation, and other measures of mental effort, are the same ones that are reflected in the duration of name-related gazes" (p. 222).

If gaze durations reflect attentional demand and attribute removal increases the attentional demand of color naming, removal should lead to an increase in gaze durations. In contrast, if attribute removal decreases the attentional demand of color naming, removal should decrease gaze durations. Measuring gaze durations allows for the assessment of effects on attentional demand even when the effects are not reflected in mean RTs (Roelofs, 2007, 2008c). For example, Korvorst, Roelofs, and Levelt (2006) observed that gaze durations may reflect the complexity of vocal utterances even when corresponding vocal RTs do not. Note that the reverse should not hold: If the latency of gaze shifting reveals attentional demand, experimental manipulations that affect RT should also be reflected in the corresponding gaze durations. Important for the present study is that gaze durations reflect attentional demand (as supported by the literature), regardless of whether they are a better measure of the attentional demand of Stroop task performance than mean RTs.

In the experiments that are reported in the present article, participants were presented with color-word Stroop stimuli displayed on the left side of a computer screen and left- or right-pointing arrows (i.e., $<$ or $>$ flanked by two Xs) displayed on the right side of the screen (cf. Roelofs, 2007, 2008b, 2008c, 2008d; Roelofs & Lamers, 2007). The manual task involving the arrows was added to the experiments to give the participants a reason to move their eyes away from the color-word stimulus (cf. Roelofs, 2008c). The Stroop stimulus and the arrow were displayed simultaneously on the screen. The participants' tasks were to vocally name the color and to manually indicate the direction in which the arrow was pointing by pressing a left or right button. The speed and accuracy of color naming was recorded. In addition, eye movements were tracked in order to determine the onset of the shift of gaze between the color and the arrow. Figure 1 illustrates the experimental set-up.

In addition to assessing the attentional demands of color naming at the short and long exposure durations, Experiment 1 tested an important prediction of both the capacity and disengagement accounts that has not been tested before. According to both accounts, removing the ink color should not only reduce Stroop interference in color naming (i.e., the difference in RTs between incongruent and neutral trials), but also diminish Stroop facilitation (i.e., the difference in RTs between congruent and neutral trials). The predicted reduced facilitation is also counterintuitive at first sight: Whereas participants look at congruent color words only for most of the trial, Stroop facilitation is predicted to be less. The experiment tested the prediction that removing the color attribute shortly after stimulus onset reduces both interference and facilitation.

In the experiments of Lamers and Roelofs (2007), perceptual grouping factors were manipulated while color-word presentation duration was kept constant. As indicated, La Heij et al. (2001) obtained some evidence that removing both color and word attributes shortly after stimulus presentation onset reduced Stroop interference. This finding suggests that exposure duration per se plays a role in addition to grouping factors. Experiment 2 examined the effect of complete stimulus removal on interference as well as facilitation.

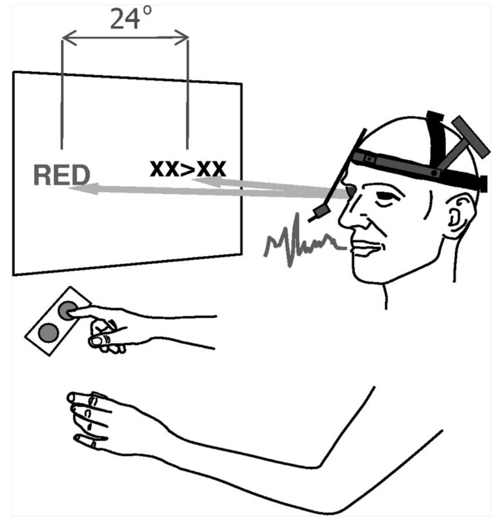

Figure 1. Schematic illustration of the experimental set-up used in Experiments 1 and 2. On each trial, participants named the color attribute of a color-word Stroop stimulus and shifted their gaze to an arrow stimulus to manually indicate its direction. The Stroop stimuli were colored words or Xs (e.g., the word RED in green ink). The latencies of vocal responding and gaze shifting were recorded.

In summary, I report two experiments in which the role of attribute exposure duration in naming performance was examined by tracking eye movements. In particular, the experiments tested whether reducing exposure duration increases or decreases gaze shift latencies. If attribute removal increases gaze durations, this would support the attentional capacity account. This account holds that color processing in the removed condition requires more attentional capacity, so that less capacity is available for distractor processing and its interfering effect will be less. In contrast, if attribute removal decreases gaze durations, this would support the attentional disengagement account. The account holds that attribute removal causes attention to disengage earlier from the distractor than with continuous presentation, so that the distractor will be processed less extensively and its interfering effect will be less. Consequently, the attentional demand of color naming will be less. In addition, Experiment 1 tested whether the reduced interference in the color-removed condition is accompanied by reduced facilitation, and Experiment 2 examined the influence of removing both color and word attributes on interference and facilitation.

Experiment 1

In the first experiment, the participants' tasks were to name the ink color of the color-word stimulus (displayed on the left of a black computer screen) and to manually indicate the direction in which an arrow was pointing (displayed on the right of the screen), as illustrated in Figure 1. The latencies of the vocal responses and gaze shifts were recorded. The color attribute was congruent with the color word (e.g., the word RED in red ink) or it was incongruent (e.g., the word RED in green ink). A series of colored Xs served as neutral stimulus. The ink color was presented throughout the trial, henceforth the *long exposure duration* condition, or the ink color was changed into neutral white color 100 ms after color presentation onset, henceforth the *short exposure duration* condition. Although the capacity and disengagement accounts both predict that color attribute removal should reduce Stroop interference and facilitation in the RTs, the accounts differ in their predictions concerning gaze durations. The capacity account predicts that attribute removal increases gaze durations, whereas the disengagement account predicts decreased gaze durations.

Method

Participants. The experiment was carried out with a group of 24 participants, who were young adult students at Radboud University Nijmegen. All participants were native speakers of Dutch. They were paid 5 Euro for their participation.

Materials and design. The stimuli consisted of the Dutch color words *rood* (*red*), *groen* (*green*), and *blauw* (*blue*) and the corresponding ink colors. The words were presented in 36-points lowercase Arial font. In addition, a row of 5 Xs served as stimulus in the neutral condition. On average, the words and Xs subtended 2.3° vertically and 6.3° horizontally at a viewing distance of 50 cm. The arrow stimuli consisted of < or > flanked by two Xs on each side (yielding XX < XX and XX > XX as stimuli). The Xs were used to demand that the arrows were foveated and to minimize the chance that participants could identify the direction of the arrows by their peripheral vision (cf. Roelofs, 2008b, 2008c). The arrow stimuli XX < XX and XX > XX were presented in 28-point uppercase Arial font, subtending 1.1° vertically and 4.6° horizontally. The horizontal distance between the middle of the color-word stimuli and the arrow stimuli was 24°. The stimuli were presented on a black background. The color of the word depended on the Stroop condition and the color of the arrow was always white.

With three ink colors, three color words, and a series of Xs, there are six possible color-word combinations in the incongruent condition, but only three combinations in the congruent condition and three in the neutral condition. In order to have an equal number of stimuli in each of the Stroop conditions, incongruent trials were therefore constructed by repeatedly pairing one color word with one ink color (i.e., ROOD–blue, GROEN–red, BLAUW–green). Thus, there were 3 congruent pairings (ROOD in red ink, GROEN in green ink, and BLAUW in blue ink), 3 incongruent pairings (ROOD in blue ink, GROEN in red ink, and BLAUW in green ink), and 3 neutral pairings (XXXXX in red, green, and blue ink). Roelofs (2010a) observed that the yoking of colors with words does not affect the time course of Stroop effects compared with fully crossing colors and words. Moreover, whereas La Heij et al. (2001) fully crossed colors and words, Lamers and Roelofs (2007) yoked particular colors with words. Nevertheless, color removal reduced Stroop interference in both studies. Thus, Stroop effects are consistent regardless of whether incongruent trials are generated in a yoked fashion compared with when words and colors are fully crossed.

The first independent variable was *Stroop condition* (congruent, incongruent, neutral). The second independent variable was *exposure duration* (long, short). The ink color was present throughout a trial (long) or it was changed into white color 100 ms after stimulus onset (short). There were two dependent variables concerning latencies, henceforth referred to as *measure*: vocal response and gaze shift. In addition, errors in vocal responding were recorded, which are defined below. Each stimulus was repeated eight times per Stroop condition and exposure duration condition, which yielded 144 trials in total. The order of presenting the stimuli and exposure durations across trials was random, except that repetitions of stimuli on successive trials were not permitted.

Apparatus. Materials were presented on a 39 cm ViewSonic 17PS screen. Eye movements were measured using an SMI EyeLink-HiSpeed 2D headband-mounted eyetracking system (SensoMotoric Instruments GmbH, Teltow, Germany). The eyetracker was controlled by a Pentium 90 MHz computer. The experiment was run under the Nijmegen Experiment Setup (NESU) with a NESU button box on a Pentium 400 MHz computer. The participants' utterances were recorded over a Sennheiser ME400 microphone to a SONY DTC55 digital audio tape (DAT) recorder. Vocal response latencies were measured using an electronic voice key.

Procedure. The participants were tested individually. They were seated in front of the computer monitor, a panel with a left and a right push button, and the microphone. The distance between participant and screen was approximately 50 cm. Participants were given written instructions telling them how their eyes would be monitored and what the task was. The experimenter also orally described the eye tracking equipment and restated the instructions. The participants were told that they had to name the ink color of color-word stimuli presented on the left side of a computer screen and manually respond by pressing a left or right button in response to the arrows presented on the right side of the screen. The participants were asked to respond as quickly as possible without making mistakes.

When a participant had read the instructions, the headband of the eyetracking system was placed on the participant's head and the system was calibrated and validated. For pupil-to-gaze calibration, a grid of three by three positions had been defined. During a calibration trial, a fixation target appeared once, in random order, in each of these positions for one second. Participants were asked to fixate upon each target until the next target appeared. After the calibration trial, the estimated positions of the participant's fixations and the distances from the fixation targets were displayed to the experimenter. Calibration was considered adequate if there was at least one fixation within 1.5° of each fixation target. When calibration was inadequate, the procedure was repeated, sometimes after adjusting the eye cameras. Successful calibration was followed by a pupil-to-gaze validation trial. For the participants, this trial did not differ from the calibration trial, but the data collected during the validation trial were used to estimate the participants' gaze positions, and the error (i.e., the distance between the estimated gaze position and the target position) was measured. Validation was considered completed if the average error was below 1.0° and the worst error below 1.5°. Depending on the result of the validation trial, the calibration and validation trials were repeated or testing began.

After successful calibration and validation, a block of 18 practice trials was administered. During the practice block, participants named all stimuli in all Stroop conditions, once in the long exposure and once in the short exposure condition. On each trial, they shifted gaze to the arrow to indicate its direction. The order of Stroop and exposure conditions was random. The practice trials were followed by the 144 experimental trials. The structure of a trial was as follows. A trial started by the simultaneous presentation of the left (color-word) and right (arrow) stimuli. Except for the color attribute in the short exposure-duration condition, the stimuli remained on the screen until the participant pushed one of the buttons in response to the arrow. The latencies of the vocal responses were measured from stimulus presentation onset. Before the start of the next trial there was a blank interval of 1.5 s. The position of the left and right eyes was determined every 4 ms. Drift correction occurred automatically after every eight trials.

Analyses. To determine the speakers' gaze shift latencies, their eye fixations were classified as falling within or on the outer contours of the Stroop stimulus or elsewhere. Although viewing was binocular and the positions of both eyes were tracked, only the position of the right eye was analyzed. The gaze shift latency was defined as the time interval between the onset of the Stroop stimulus and the end of the last eye fixation at the stimulus before a saccade to the arrow was initiated. Because the Stroop stimuli were always presented in the same position on the screen, there was no fixation point to indicate the position of the stimuli before trial onset. At the beginning of a trial, participants were virtually always fixating the position where the Stroop stimulus would come up. Gaze shifts latencies were measured from the onset of the color-word stimulus.

A naming response was considered to be invalid when it included a speech error, when a wrong word was produced, or when the voice key was triggered incorrectly. Error trials were discarded from the analyses of both the naming latencies and gaze durations. The vocal response latencies, gaze shift latencies, and errors were submitted to analyses of variance (ANOVAs). To test for Stroop interference effects, the latencies and errors in the incongruent and neutral conditions were compared. To test for facilitation effects, the congruent and neutral conditions were compared. For all comparisons, an alpha level of .05 was adopted. Stroop condition and exposure duration effects were also compared between measures (vocal, gaze). To correct for the difference in absolute latencies between measures, the comparisons of the magnitude of effects were performed on standard scores (z) with zero mean and unit standard deviation (cf. Roelofs, 2007). Standard scores are frequently used to obtain comparability of observations obtained by different measurements (Winer, Brown, & Michels, 1991).

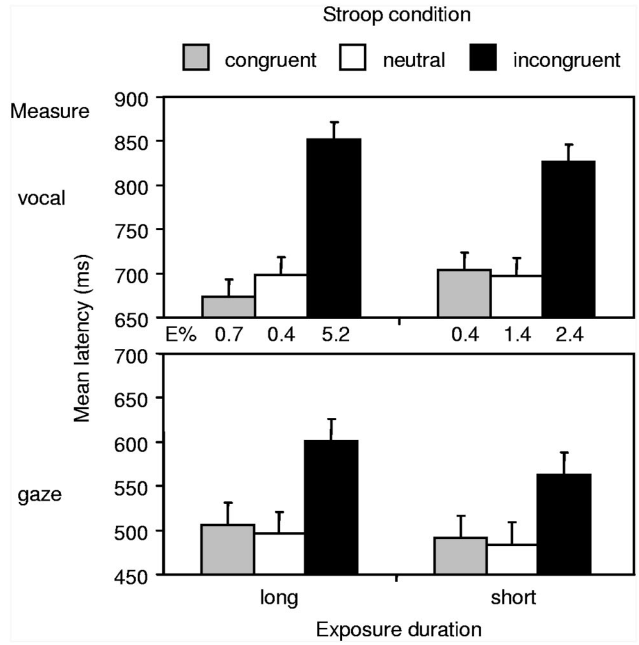

Figure 2. Speed and accuracy of performance in Experiment 1 for Stroop condition (congruent, neutral, incongruent) and exposure duration (long, short). Shown are the mean vocal response latencies and error percentages (upper panel) and the mean gaze shift latencies (lower panel). E% = error percentage. Error bars indicate the standard error of the mean.

Results and Discussion

Figure 2 displays for each Stroop condition and exposure duration condition the mean latencies for the vocal responses and gaze shifts. The figure shows that the latencies were longer in the incongruent than the neutral condition regardless of exposure duration and measure. The mean color naming RT was smaller on congruent than neutral trials at the long exposure duration but not at the short duration. There was no difference between congruent and neutral trials in the gaze durations regardless of exposure duration. The figure also indicates that most errors in color naming were made in the incongruent conditions.

The statistical analysis of the errors in color naming yielded effects of Stroop condition, $F(2, 46) = 16.88$, $p < .001$, $\eta_p^2 = .42$, but not of exposure duration, $F(1, 23) = 1.27$, $p = .27$, $\eta_p^2 = .05$. Stroop condition and exposure duration interacted, $F(2, 46) = 4.22$, $p < .02$, $\eta_p^2 = .16$. Planned comparisons revealed that at the long exposure duration more errors were made on incongruent than neutral trials, $t(23) = 3.89$, $p < .001$, whereas the congruent and neutral trials did not differ, $t(23) < 1$, $p = .43$. At the short exposure duration, the error rate did not differ between incongruent and neutral trials, $t(23) = 1.3$, $p = .20$, and also not between congruent and neutral trials, $t(23) = 1.4$, $p = .19$. The difference in errors between incongruent and neutral trials was larger at long than short exposure durations, $t(23) = 2.77$, $p < .01$, whereas there was no such difference between durations for congruent and neutral trials, $t(23) = 1.35$, $p = .19$. Thus, compared with neutral trials, the removal of the color attribute reduced the number of errors on incongruent trials, whereas it had no influence on congruent trials.

The statistical analysis of the color naming RTs yielded effects of Stroop condition, $F(2, 46) = 146.38$, $p < .001$, $\eta_p^2 = .86$, but not of exposure duration, $F(1, 23) < 1$, $p > .65$, $\eta_p^2 = .01$. Stroop condition and exposure duration interacted, $F(2, 46) = 7.20$, $p < .002$, $\eta_p^2 = .24$. Planned comparisons revealed that color naming RT at the long exposure duration was longer on incongruent than neutral trials, $t(23) = 10.89$, $p < .001$, and shorter on congruent than on neutral trials, $t(23) = 2.78$, $p = .005$. Moreover, color naming RT at the short exposure duration was longer on incongruent than neutral trials, $t(23) = 11.44$, $p < .001$, but the congruent and neutral trials did not differ, $t(23) = 0.50$, $p > .63$. The interference was marginally larger at long than short exposure durations, $t(23) = 1.54$, $p < .07$, and the facilitation was larger at long than short exposure durations, $t(23) = 3.10$, $p < .002$. Thus, the removal of the color attribute reduced interference (replicating earlier findings in the literature) and importantly, also reduced facilitation. However, exposure duration had no main effect on the RTs.

The statistical analysis of the gaze shift latencies yielded effects of Stroop condition, $F(2, 46) = 50.87$, $p < .001$, $\eta_p^2 = .69$, and of exposure duration, $F(1, 23) = 6.53$, $p < .018$, $\eta_p^2 = .22$. The latter reflects that gaze shift latencies were longer at the long than the short exposure durations (respectively, 534 ms and 513 ms). Stroop condition and exposure duration did not interact, $F(2, 46) = 2.08$, $p = .14$, $\eta_p^2 = .08$. Thus, the removal of the color attribute reduced gaze durations regardless of Stroop condition.

The statistical analysis of the *z*-scores comparing the latency effects between the vocal responses and gaze shifts yielded an effect of Stroop condition, $F(2, 46) = 137.40$, $p < .001$, $\eta_p^2 = .86$, but not a main effect of exposure duration, $F(1, 23) = 2.77$, $p = .11$, $\eta_p^2 = .11$. The effect of exposure duration differed between measures, $F(1, 23) = 9.26$, $p < .006$, $\eta_p^2 = .29$, and this also held for the effect of Stroop condition, $F(2, 46) = 15.68$, $p < .001$, $\eta_p^2 = .41$. Stroop condition and exposure duration interacted, $F(2, 46) = 4.97$, $p < .011$, $\eta_p^2 = .18$, and the interaction differed between measures, $F(2, 46) = 4.33$, $p < .019$, $\eta_p^2 = .16$. These *z*-score analyses indicate that the effect of exposure duration is different for the vocal RTs and the gaze durations. Whereas removing the color attribute reduced interference and facilitation in the naming latencies, it reduced gaze durations regardless of Stroop condition.

The stability of the observations for the overall mean latencies was assessed by examining the latency distributions (Luce, 1986). To obtain the latency distributions, I divided the rank-ordered latencies for each participant into deciles (10% quantiles) and computed mean latencies for each decile, separately for the Stroop conditions and exposure durations for both the vocal responses and gaze shifts (cf. Lamers & Roelofs, 2007; Roelofs, 2008a, 2008b, 2008c). By averaging these means across participants, Vincentized cumulative distribution functions are obtained (Ratcliff, 1979). Vincentizing the latency data across individual participants provides a way of averaging data while preserving the shapes of the individual distributions. Figure 3 shows the distributional plots.

Figure 3 shows that the effect of exposure duration on vocal responding is different for congruent and incongruent trials, whereas the neutral trials exhibited no duration effect, regardless of the relative speed of responding. These observations were confirmed by statistical analysis. ANOVAs were performed with exposure duration, Stroop condition, and decile as within-subject factors (cf. Balota, Yap, Cortese, & Watson, 2008; De Jong, Berendsen, & Cools, 1999). Exposure duration and Stroop condition interacted, $F(2, 46) = 6.41$, $p < .003$, $\eta_p^2 = .22$, and the interaction was independent of decile, $F(18, 414) < 1$, $p = .57$, $\eta_p^2 = .04$. Vocal responding on congruent trials was faster at the long than the short exposure duration, $t(23) = 3.71$, $p = .001$, and there was no interaction with decile, $F(9, 207) < 1$, $p = .47$, $\eta_p^2 = .04$. On neutral trials, vocal responding did not differ between the exposure durations, $t(23) < 1$, $p = .93$, regardless of decile, $F(9, 207) < 1$, $p = .93$, $\eta_p^2 = .02$. On incongruent trials, vocal responding was marginally faster at the short than the long exposure duration, $t(23) = 1.66$, $p = .055$, and there was a marginal interaction with decile, $F(9, 207) = 1.69$, $p = .09$, $\eta_p^2 = .07$. Thus,

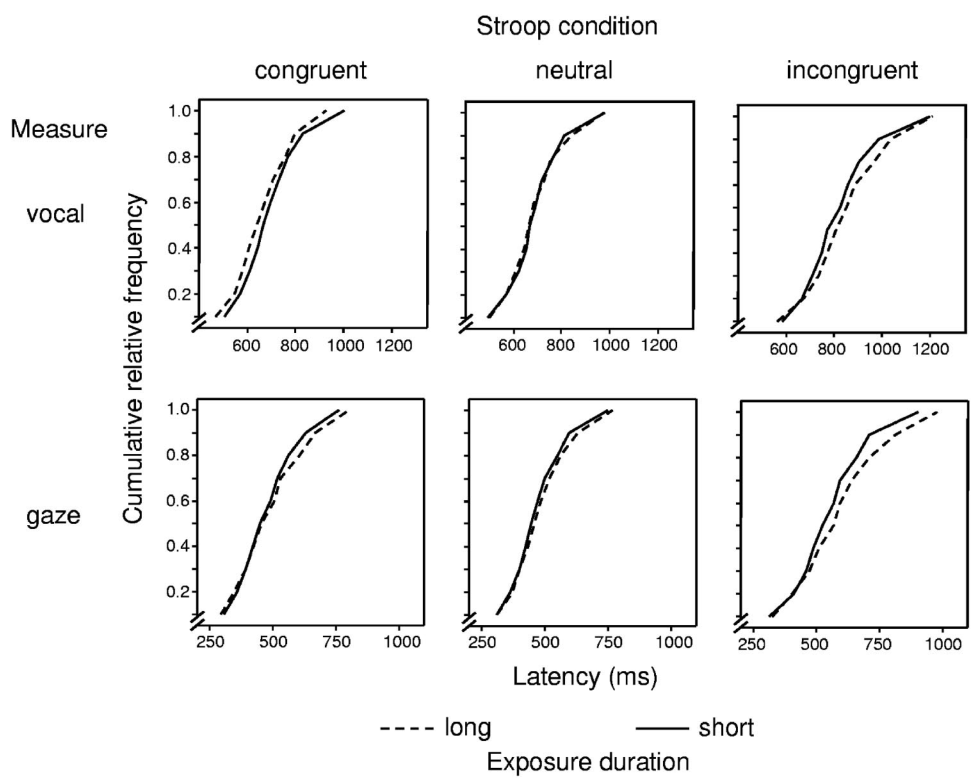

Figure 3. Vincentized cumulative distribution curves for the vocal responses and gaze shifts per Stroop condition and exposure duration in Experiment 1.

the effect of exposure duration on vocal responding differs between congruent and incongruent trials, whereas the neutral trials exhibited no effect, throughout the latency range. Figure 3 also shows that, different from the vocal responses, the onset of gaze shifts tended to occur earlier at the short than the long exposure duration regardless of Stroop condition. There was no interaction of exposure duration and Stroop condition, $F(2, 46) = 2.30$, $p = .11$, $\eta_p^2 = .09$, and no dependence on decile, $F(18, 414) < 1$, $p = .80$, $\eta_p^2 = .03$. Thus, the reduced Stroop interference and facilitation in the vocal response latencies is associated with generally reduced gaze durations, suggesting diminished attentional demand.

To summarize, removing the color attribute reduced interference and facilitation in the color naming RTs. Moreover, removing the color attribute reduced gaze durations, which suggests that the attentional demand of color naming was less at the short than the long exposure duration. This challenges the attentional capacity account and supports the attentional disengagement account of the exposure duration effect.

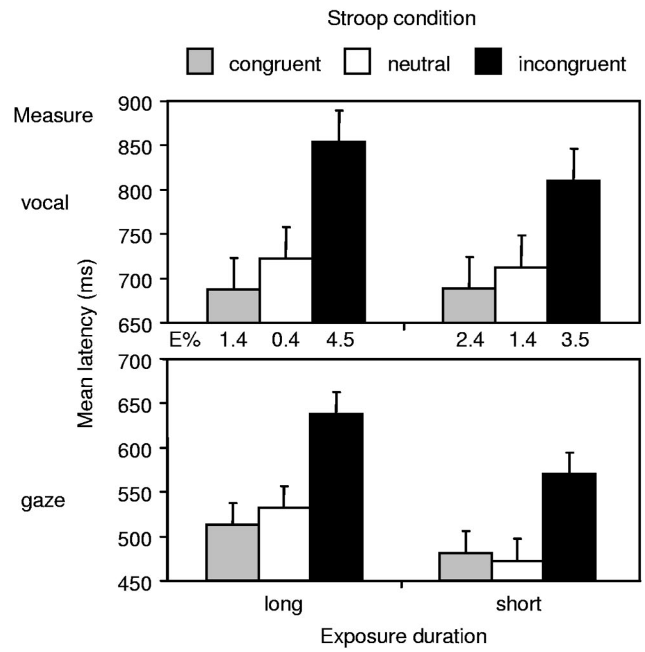

Figure 4. Speed and accuracy of performance in Experiment 2 for Stroop condition (congruent, neutral, incongruent) and exposure duration (long, short). Shown are the mean vocal response latencies and error percentages (upper panel) and the mean gaze shift latencies (lower panel). E% = error percentage. Error bars indicate the standard error of the mean.

Experiment 2

La Heij et al. (2001) presented some evidence that removing both color and word attributes shortly after stimulus presentation onset reduced the magnitude of Stroop interference. This finding suggests that exposure duration per se plays a role in addition to Gestalt grouping factors (cf. Lamers & Roelofs, 2007). The second experiment examined the effect of complete stimulus removal on interference as well as facilitation in both the color naming RTs and gaze shift latencies.

Method

Participants. The experiment was run with 12 new participants from the same subject population as in the first experiment.

Materials and design. The experiment used displays that were identical to those of Experiment 1 except that in the short exposure condition, the complete color-word Stroop stimulus was removed from the screen 100 ms after stimulus onset. Exposure duration (long, short) was again randomized across trials. Latencies of vocal responding and gaze shifting were measured at both short (100 ms) and long (whole trial) exposure durations of the color-word Stroop stimuli.

Apparatus, procedure, and analyses. These were the same as in Experiment 1. On each trial, the complete color-word Stroop stimulus was removed from the screen after 100 ms (short duration condition) or the stimulus remained present until trial offset (long exposure condition).

Results and Discussion

Figure 4 displays for each Stroop condition and exposure duration the mean latencies for the vocal responses and gaze shifts. The figure shows that the latencies were longer in the incongruent than the neutral condition regardless of exposure duration and measure. The mean color naming RT was smaller on congruent than neutral trials at both the long and short exposure durations, but there was no such consistent difference between congruent and neutral trials in the gaze durations. The figure also indicates that most errors in color naming were made in the incongruent conditions.

The statistical analysis of the errors in color naming yielded effects of Stroop condition, $F(2, 22) = 4.50$, $p < .02$, $\eta_p^2 = .29$, but not of exposure duration, $F(1, 11) < 1$, $p = .67$, $\eta_p^2 = .02$. Stroop condition and exposure duration did not interact, $F(2, 22) < 1$, $p = .56$, $\eta_p^2 = .05$. Comparisons revealed that more errors were made on incongruent than neutral trials, $t(23) = 2.38$, $p < .04$, whereas the error rates on congruent and neutral trials did not differ, $t(23) = 1.08$, $p = .30$. Thus, compared with neutral trials, the removal of the color attribute reduced the number of errors on incongruent trials, whereas it had no influence on congruent trials.

The statistical analysis of the color naming RTs yielded effects of Stroop condition, $F(2, 22) = 54.78$, $p < .001$, $\eta_p^2 = .83$, but not of exposure duration, $F(1, 11) = 2.91$, $p > .12$, $\eta_p^2 = .21$. Stroop condition and exposure duration interacted, $F(2, 22) = 4.03$, $p < .03$, $\eta_p^2 = .27$. Planned comparisons revealed that color naming RT at the long exposure duration was longer on incongruent than neutral trials, $t(11) = 6.80$, $p < .001$, and shorter on congruent than on neutral trials, $t(11) = 2.74$, $p < .01$. Moreover, color naming RT at the short exposure duration was longer on incongruent than neutral trials, $t(11) = 5.42$, $p < .001$, and marginally shorter on congruent than on neutral trials, $t(11) = 1.60$, $p = .07$. The interference was larger at long than short exposure durations, $t(11) = 2.32$, $p < .02$, whereas the facilitation did not differ between exposure durations, $t(11) < 1$, $p = .55$. Thus, the removal of the whole Stroop stimulus reduced interference but did not have an effect on facilitation. Exposure duration had no main effect on the RTs.

The statistical analysis of the gaze shift latencies yielded effects of Stroop condition, $F(2, 22) = 15.34$, $p < .001$, $\eta_p^2 = .58$, and of exposure duration, $F(1, 11) = 13.89$, $p < .003$, $\eta^2_p = .56$. The latter reflects that gaze shift latencies were longer at the long than the short exposure durations (respectively, 561 ms and 508 ms). There was a marginal interaction of Stroop condition and exposure duration, $F(2, 22) = 2.92$, $p = .08$, $\eta^2_p = .21$. Given that the interaction approached significance, the presence of a duration effect for each of the Stroop conditions was assessed by pairwise comparisons. Gaze shifts occurred earlier at the short than the long exposure durations for the congruent trials, $t(11) = 2.11$, $p < .03$, for the neutral trials, $t(11) = 3.58$, $p < .002$, and for the incongruent trials, $t(11) = 3.63$, $p < .002$. Thus, the removal of the whole Stroop stimulus reduced gaze shift latencies regardless of Stroop condition.

The statistical analysis of the *z*-scores comparing the latency effects between the vocal responses and gaze shifts yielded an effect of Stroop condition, $F(2, 22) = 24.79$, $p < .001$, $\eta^2_p = .69$, and an effect of exposure duration, $F(1, 11) = 15.94$, $p < .002$, $\eta^2_p = .59$. The effect of exposure duration differed between measures, $F(1, 11) = 8.93$, $p < .01$, $\eta^2_p = .45$, and there was also a marginal interaction of measure and Stroop condition, $F(2, 22) = 3.13$, $p = .064$, $\eta^2_p = .22$. Stroop condition and exposure duration interacted, $F(2, 22) = 5.19$, $p < .014$, $\eta^2_p = .32$, but the interaction did not depend on measure, $F(2, 22) < 1$, $p = .52$, $\eta^2_p = .06$. These *z*-score analyses indicate that the main effect of exposure duration differed between the vocal RTs and the gaze durations, but the interaction between exposure duration and Stroop condition is similar for the two measures.

The stability of the observations for the overall mean latencies was again assessed by examining the latency distributions. Because fewer participants were tested in the present experiment than in Experiment 1, I increased the number of data points per quantile by using quintiles (20% quantiles) instead of deciles. I divided the rank-ordered latencies for each participant into quintiles and computed mean latencies for each quintile, separately for the Stroop conditions and exposure durations for both the vocal responses and gaze shifts. Figure 5 shows the distributional plots.

Figure 5 shows that vocal responding on incongruent trials was slower at long than short exposure duration, whereas there was no effect of exposure duration on congruent trials, regardless of the relative speed of responding. On neutral trials, vocal responding was slower at long than short exposure duration except for the fastest responses. Exposure duration and Stroop condition interacted, $F(2, 22) = 4.72$, $p < .02$, $\eta^2_p = .30$, and this interaction was independent of quintile, $F(8, 88) = 1.61$, $p = .14$, $\eta^2_p = .13$. Figure 5 also shows that, different from the vocal responses, the onset of gaze shifts tended to occur earlier at the short than the long exposure duration regardless of Stroop condition. There was an interaction of exposure duration and Stroop condition, $F(2, 22) = 3.60$, $p = .045$, $\eta^2_p = .25$, and this interaction depended marginally on quintile, $F(8, 88) = 1.86$, $p = .077$, $\eta^2_p = .15$. On congruent trials, gaze shifts occurred later at long than short exposure duration, $t(11) = 1.97$, $p = .04$, and this effect was independent of quintile, $F(4, 44) < 1$, $p = .51$, $\eta^2_p = .07$. On neutral trials, gaze shifts occurred later at long than short exposure duration, $t(11) = 3.55$, $p = .001$, and this effect increased with quintile, $F(4, 44) = 7.87$, $p = .001$, $\eta^2_p = .42$. On incongruent trials, gaze shifts occurred later at long than short exposure duration, $t(11) = 3.91$, $p = .001$, and this effect was independent of

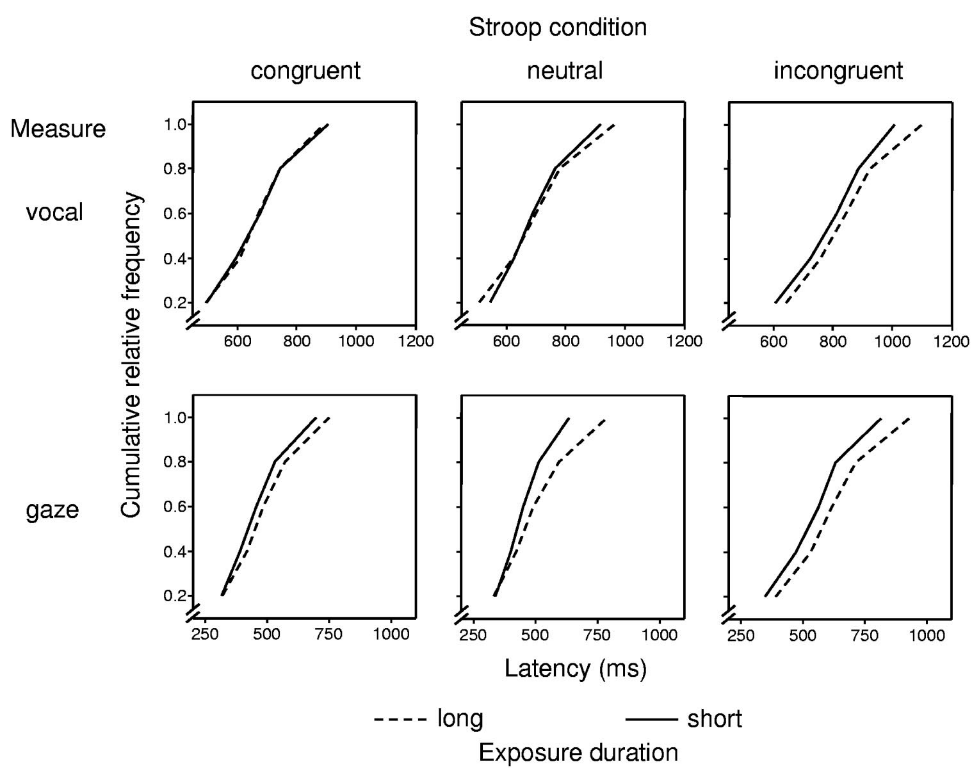

Figure 5. Vincentized cumulative distribution curves for the vocal responses and gaze shifts per Stroop condition and exposure duration in Experiment 2.

quintile, $F(4, 44) = 1.38$, $p = .26$, $\eta_p^2 = .11$. Thus, gaze shift latencies were longer at long than short exposure durations, and the magnitude of this effect was independent of relative latency except for the neutral condition. Thus, the reduced Stroop interference in the vocal response latencies is associated with generally reduced gaze durations, suggesting diminished attentional demand.

To summarize, removing the whole Stroop stimulus reduced interference but not facilitation in the color naming RTs. Moreover, whereas removal did not have a main effect on the vocal RTs, it reduced gaze durations, which suggests that the attentional demand of color naming was less at the short than the long exposure durations. The evidence from the gaze durations challenges the attentional capacity account and supports the attentional disengagement account of the exposure duration effect.

General Discussion

The experiments reported in the present article examined the role of attribute exposure duration in naming performance by tracking eye movements. Does reducing exposure duration of the color attribute or the complete color-word stimulus increase or decrease gaze durations in Stroop task performance? If removal increases gaze durations, this would support the attentional capacity account of exposure duration effects in the Stroop task. This account holds that color processing in the removed condition requires more attentional capacity, so that less capacity is available for distractor processing and its interfering effect will be less. In contrast, if attribute removal decreases gaze durations, this would support the attentional disengagement account of exposure duration effects in the Stroop task. The account holds that attribute removal causes attention to disengage earlier from the distractor, so that the distractor will be processed less extensively and its interfering effect will be less. Consequently, the attentional demand of color naming will be less. In addition, Experiment 1 tested whether the reduced interference in the color-removed condition is accompanied by reduced facilitation in color naming RTs, and Experiment 2 examined the influence of removing both color and word attributes on interference and facilitation in RTs.

In both experiments, participants were presented with color-word Stroop stimuli and left- or right-pointing arrows. They vocally named the color attribute and shifted their gaze to the arrow to manually indicate its direction. The color attribute (Experiment 1) or the complete color-word stimulus (Experiment 2) was removed 100 ms after stimulus onset. Compared with continuous presentation, removing the color attribute diminished Stroop interference as well as facilitation effects in color naming RTs (Experiment 1), whereas removing the complete stimulus diminished interference only (Experiment 2). Attribute and stimulus removal reduced the latency of gaze shifting in both experiments, which suggests decreased rather than increased attentional demand. These results suggest that reduced exposure duration contributes to attribute naming performance by diminishing the extent to which irrelevant attributes are processed, which reduces attentional demand. The present findings challenge the attentional capacity account and support the attentional disengagement account of the exposure duration effect.

In the remainder of this article, three issues are discussed. I address the issue of the source of Stroop facilitation in the experiments, the role of attentional disengagement, and the attentional demand of naming performance.

The Source of Stroop Facilitation

In Experiment 1, attribute removal influenced both interference and facilitation in the color naming RTs, whereas removal of the complete stimulus only affected interference in the RTs in Experiment 2. Some researchers have argued that such differential effect of an experimental variable on interference and facilitation suggests that interference and facilitation have a different source (Kane & Engle, 2003; MacLeod & MacDonald, 2000). In particular, it has been suggested that whereas interference reflects competition in response selection on incongruent trials, facilitation reflects inadvertent reading of the color word on some of the congruent trials (but see Roelofs, 2010a). The present data on the effect of removal would then suggest that inadvertent reading occurs less frequently when the color attribute is removed while the word remains present than when the color is present until trial offset (Experiment 1). Moreover, the data would suggest that the frequency of inadvertent reading does not differ between the condition in which both color and word stay and the condition in which both disappear (Experiment 2).

The inadvertent reading hypothesis needs to assume that reading occurs on only a few trials, because if inadvertent reading occurs on all congruent trials, the magnitude of facilitation should have been much bigger than observed. Whereas oral reading is typically some 100-200 ms faster than color naming (e.g., Glaser & Glaser, 1982, 1989), the facilitation in Experiment 1 was only some 25 ms. This facilitation effect may reflect a constant speed up of about 25 ms on every congruent trial compared with neutral trials. If so, the cumulative distribution curve for congruent trials should be just that for neutral trials except that the former is shifted to the left by about 25 ms. In contrast, if the facilitation stemmed from a 100-200 ms speed up that occurred only on a small proportion of the congruent trials, the effect on the mean RT might be the same, but the effect on the RT distributions should be different. The RT distributions in the congruent and neutral conditions should then differ among the short RTs (i.e., the lower deciles of the cumulative distribution curve) but converge at the longer RTs (the upper deciles). In Experiment 1, the difference between congruent and neutral trials did not interact with decile, $F(9, 207) < 1$, $p > .69$, $\eta_p^2 = .03$, which suggests that the congruent stimuli yielded a constant small speed up rather than an occasional large speed up because of inadvertent reading. Thus, the results of Experiment 1 suggest that the facilitation did not arise because of an occasional reading trial.

Moreover, interference and facilitation effects may have a common ground and still be differentially affected by experimental manipulations (observed in Experiment 2), as has been demonstrated theoretically by means of computer simulations using the WEAVER++ model of Stroop task performance (Roelofs, 2003). In this model, converging information on the word and color dimensions combines to produce facilitation of the process of color name selection on congruent trials, just as divergent information causes interference of color name selection on incongruent trials. Facilitation shifts the cumulative distribution curve leftward and interference shifts it rightward (Roelofs, 2008a). It is important to note that reducing the duration of distractor word processing in the model may reduce interference without affecting facilitation, as empirically observed in the present Experiment 2. In the model, there is no upper limit on the amount of interference, but there is a limit on facilitation. As a consequence, interference is more sensitive to manipulations of exposure duration than is facilitation in the model (Roelofs, 2003), in agreement with the results of Experiments 1 and 2. To conclude, the finding that manipulations of exposure duration may affect interference and facilitation differently is compatible with the assumption that interference and facilitation arise from the same underlying processing mechanism.

Role of Attentional Disengagement

Previous work by Chen (2003) suggested that increasing perceptual load in manual Stroop task performance increases interference. The present data do not agree with the finding of Chen (2003). This difference in results between studies provides additional evidence that removal of the color attribute or the complete Stroop stimulus diminishes perceptual load, as the gaze durations in Experiments 1 and 2 suggested. The gaze durations support the assumption that removal causes attention to disengage earlier from the stimulus, so that the distractor will be processed less extensively and its interfering effect will be less. Consequently, the attentional demand of color naming will be less, as reflected in the gaze durations. The present findings provide further support for the assumption that words in the Stroop task are processed to the extent that they receive attention rather than being processed automatically. Thus, Stroop effects do not provide evidence for the automaticity of reading, as is often assumed (e.g., MacLeod, 1991; Posner & Snyder, 1975), but rather indicate the difficulty of not allocating attention to the word in this task (cf. Kahneman, 1973; Kahneman & Henik, 1981; Pashler, 1998). Accumulating evidence suggests that word reading is not an automatic process but requires attention (e.g., Besner, Stolz, & Boutilier, 1997; Besner & Stolz, 1999a, 1999b; Lachter, Forster, & Ruthruff, 2005; Reichle, Liversedge, Pollatsek, & Rayner, 2009; Reichle, Rayner, & Pollatsek, 2003; Risko, Stolz, & Besner, 2005; Stolz & Besner, 1996).

Evidence suggests that spatial attention is required for visual word identification (e.g., Lachter et al., 2005) and that central attention is needed for spelling-to-sound conversion in reading aloud (e.g., Besner, Reynolds, & O'Malley, 2009; Paulitzki, Risko, O'Malley, Stolz, & Besner, 2009; Reynolds & Besner, 2006). Lachter et al. (2005) had participants decide whether letter strings were words or not, while masked prime words were presented at attended or unattended locations. The masked primes influenced the lexical decisions to the targets, but only when the primes were attended. However, Lachter et al. (2008) observed that in Stroop task performance, unattended masked words may yield a Stroop effect, suggesting that lexical processing can sometimes occur outside the focus of spatial attention. The magnitude of the Stroop effect (incongruent vs. congruent) obtained by Lachter et al. (2008) was maximally 16 ms in their experiments, whereas the effect is typically some 100 ms in normal Stroop task performance (e.g., Glaser & Glaser, 1982). This suggests that attention to the word much increases the magnitude of the Stroop effect. The results of the present experiments on the effect of exposure duration are in agreement with these findings.

In addition to the disengagement hypothesis, there are other alternative accounts which need to be discussed. For example, removal may cause limited processing of attributes, producing relatively weak activation of color and word representations. Consequently, Stroop interference is expected to diminish, as observed. A problem with this alternative account is that weak activation of the color and word representations may be a plausible assumption when the whole Stroop stimulus is removed from the screen (Experiment 2) but not when only the color is removed and the word remains (Experiment 1). In the latter case, word representations should remain highly activated. Thus, weak activation cannot explain the reduced interference in both experiments, whereas attentional disengagement can.

Another alternative account is that the removal of the color attribute after 100 ms in the short duration condition serves as an "abrupt offset" that attracts attention to the color (cf. Atchley, Kramer, & Hillstrom, 2000; Miller, 1989; Wright & Ward, 2008). As a result of the attentional capture, color becomes more salient and color naming is faster. A problem with the attention capture account is that Lamers and Roelofs (2007) observed that repositioning the color (their Experiment 2) and repositioning the word (their Experiment 3) reduced Stroop interference, despite the fact that moving stimuli usually attract attention, just like abrupt offsets (cf. Wright & Ward, 2008). Attention capture by the moving word should make the word more salient and increase Stroop interference, exactly opposite to what Lamers and Roelofs (2007) observed. They argued that repositioning the word (or color) breaks the grouping of color and word into one Gestalt to which attention is allocated. Consequently, the word receives less attention and Stroop interference is reduced, as empirically observed. Moreover, Lamers and Roelofs (2007) observed that the repositioning yields interference but only in the leading edge of the RT distribution, whereas facilitation from repositioning was present in the rest of the distribution and reflected in the mean RT. To conclude, the attention capture hypothesis cannot account for the reduced interference from repositioning the word, whereas attentional disengagement can.

According to the disengagement hypothesis, attribute or stimulus removal diminished attentional demand, which was reflected in the gaze durations. The shorter gaze shift latencies in the short than the long exposure conditions in the present experiments may be related to the "gap effect" in eye movement control (see Wright & Ward, 2008, for a review). In a seminal study, Saslow (1967) observed that gaze shift latencies are shorter if a fixation cross was removed 200 ms before target onset than when the fixation cross remained visible throughout a trial. The target was a stimulus appearing on the left or the right side of the fixation cross. According to Fischer and colleagues (Fischer & Breitmeyer, 1987; Fischer & Rampsperger, 1984), the shorter latency of the gaze shifts in the fixation-cross removal condition is the result of visual attention disengagement occurring prior to the saccade preparation process. When disengagement had already occurred prior to the preparation of a saccade to the left or right target, the result is a shorter latency of the gaze shift.

The experimental set-up in the present experiments, in which participants were presented with color-word Stroop stimuli and left- or right-pointing arrows, is more complex than the experimental set-up of Saslow (1967). In the present experiments, the color-word Stroop stimulus and arrow were presented simultaneously, thus the removal of the color attribute or the complete stimulus did not precede the appearance of the arrow. Still, attribute removal may help disengage visual attention and thereby reduce gaze shift latencies, as suggested by Fischer and colleagues for the experiments of Saslow (1967). Given that the effect of Stroop condition is reflected in the gaze durations in the present experiments, the onset of gaze shifts must have been determined by aspects of color word planning, such as color name selection. Thus, the present results suggest that gaze durations are determined by both early visual and central attentional factors. In picture and word naming experiments reported in Roelofs (2007), the moment of gaze shifting was also determined by both early and central factors.

To account for these observations, I proposed that participants strategically set a criterion for when gaze shifts should occur between task stimuli (Roelofs, 2007, 2008b). The tasks in the present experiments were Stroop color naming and manually responding to arrows. The position of the shift criterion within the color naming process serves to maintain acceptable levels of speed and accuracy, to minimize resource consumption and crosstalk between tasks, and to satisfy instructions about task priorities. The shift criterion is a central parameter of the attention allocation policy (cf. Kahneman, 1973; Meyer & Kieras, 1997a, 1997b). Following Meyer and Kieras (1997b), I assumed that the shift criterion may be contingently updated during the course of a trial, to take account of relevant events. The utility of this assumption was demonstrated in WEAVER++ simulations of relevant findings on naming and gaze shifting (Roelofs, 2007, 2008b). If visual attention is disengaged earlier at short than long color exposure durations, the shift criterion may be correspondingly lowered, which results in a shorter gaze duration at short than long color exposures, as observed in Experiments 1 and 2.

The results of the present experiments suggest that exposure duration influences input filtering. In performing tasks requiring selective attention, such as the color-word Stroop task, WEAVER++ employs at least two kinds of selective attention, referred to as "stimulus set" and "response set" by Broadbent (1970, 1971; Broadbent & Gregory, 1964). Stimulus set concerns input filtering and indicates selection on the basis of a perceptual attribute or source, such as spatial location, color, or shape. Response set indicates selection on the basis of the vocabulary of allowable responses (Roelofs, 2003, 2010b). In a typical Stroop experiment, the irrelevant words correspond to the allowable responses, so selection by response set is not possible. However, some kind of input filtering is possible in Stroop task performance. WEAVER++ favors processing of the color attribute over the word shape attribute by reactively blocking the latter. Reactive blocking implies that attentional modulation develops after an initial visual response to both target and distractors, in line with event-related brain potential evidence from humans (e.g., Di Russo, Martinez, & Hillyard, 2003) and neurophysiological data on monkeys (e.g., Roelfsema, Lamme, & Spekreijse, 1998). I refer to Duncan (2004) for a review.

As concerns input filtering, evidence suggests that attention to one attribute may enhance the processing of other irrelevant attributes to the extent that the attributes are "integral" or "separable" (Garner, 1974). Separable attributes can be processed independently, whereas integral attributes are processed together and attention to one attribute implies attention to both. For example, O'Craven, Downing, and Kanwisher (1999) presented neuroimaging evidence suggesting that attention to movement facilitates processing of the moving object itself. Participants were shown a face superimposed on a house. One of the two objects was moving and participants had to pay attention to the movement in one condition. It was found that a functionally defined cortical face-area was more active when the face was moving than when the house was. Similarly, a functionally defined cortical place-area was more active when the house was moving than when the face was. These findings suggests that the motion of a face or house is not completely separable from the face or house itself. Polk, Drake, Jonides, Smith, and Smith (2008) presented neuroimaging evidence that color and word attributes are separable to some extent. Participants had to manually respond to the color of color-word Stroop stimuli. Activity in a functionally defined cortical color-area increased and activity in a cortical word-area decreased on incongruent relative to neutral trials. These results suggest that processing the color of a word may be separable from processing the word itself. Verbal responses are more quickly available for words than colors, which may necessitate suppression of word processing. The decrease of word-area activity observed by Polk et al. (2008) is in line with the assumption of distractor blocking implemented in WEAVER++.

It is important to note that the presence of a Stroop effect implies that word and color are not fully separable but are processed together to some extent, as with the movement and face or house attributes in the study of O'Craven et al. (1999). This is in line with the assumption of WEAVER++ that blocking occurs after an initial phase of both color and word processing in the standard Stroop task. The data of Polk et al. (2008) leave open whether activity in the functionally defined cortical word-area would have been further reduced than observed if the color had been removed shortly after its onset, hampering the grouping of color and word intro one perceptual object, as the results of the present Experiment 1 and the experiments of Lamers and Roelofs (2007) suggest. Moreover, the data of Polk et al. leave open whether activity in the word area would have been further reduced if both color and word had been removed shortly after their presentation onset, as the results of the present Experiment 2 suggest. To conclude, the data of Polk et al. (2008) indicate that word-area activity may be reduced in Stroop task performance, but leave open whether attending the color of a color-word Stroop stimulus enhances processing of the word to some extent. The findings support the assumption of WEAVER++ that color and word processing are processed together to some extent, but that they are also partly separable so that word processing may be selectively blocked.

Attentional Demand of Naming Performance

In the present Experiment 2, participants fixated for 400-500 ms an empty region of the screen (where the color-word stimulus had been presented for the first 100 ms of a trial) before they moved their gaze to the arrow stimulus (cf. Sanders, 1998). Moreover, the gaze shift latencies reflected effects of Stroop condition in Experiments 1 and 2. The effect of Stroop condition on gaze durations provide further evidence that gaze shifts are not immediately performed after color identification, as assumed by Meyer and Kieras (1997a, 1997b) and Sanders (1998), but gaze shifts are codetermined by word planning factors, as assumed by Meyer et al. (2003) and Roelofs and Lamers (2007; Roelofs, 2007, 2008b, 2008c, 2008d). In particular, the effects of Stroop condition on the gaze shift latencies suggest that gaze shifts occurred after response selection in the present experiments. Thus, the results disconfirm the assumption that gaze shifts occur immediately after perceptual identification of the stimulus (Meyer & Kieras, 1997a, 1997b; Sanders, 1998). Still, as is evident from both experiments, gaze shifts are initiated before the onset of articulation. This implies that part of planning the vocal response happens during the execution of the gaze shift and the fixation of the arrow (cf. Sanders, 1998).

In the WEAVER++ model (Levelt, Roelofs, & Meyer, 1999; Roelofs, 1992, 1997, 2003), color naming involves the activation of nodes for color concepts, lemmas, morphemes, phonemes, and syllable motor programs in associative memory. In the model, activation spreads from level to level in memory, whereby each node sends a proportion of its activation to connected nodes. As a consequence, memory activation induced by perceived colors decreases with network distance. The activation flow from concepts to phonological nodes is limited unless attentional enhancements are involved to boost the activation (Roelofs, 1992, 2003, 2008c, 2008d).

The assumption that word planning requires attentional activation enhancements is supported by RT evidence from monitoring tasks (see Roelofs, 2003, 2008d, for review). In a study by Roelofs, Özdemir, and Levelt (2007), participants were shown pictured objects (e.g., a cat) while hearing a tone or a spoken word presented 600 ms after picture onset. When a spoken word was presented (e.g., *cup* or *house*), participants indicated whether it contained a pre-specified phoneme (e.g., /k/) by pressing a button. When the tone was presented, they indicated whether the object name contained the phoneme (Experiment 1) or they named the object (Experiments 2 and 3). Phoneme monitoring latencies for the spoken words were shorter when the object name contained the prespecified phoneme (e.g., cat—*cup*) compared with when it did not (e.g., cat—*house*). However, no priming of phoneme monitoring was obtained (Experiment 4) when the objects required no response but were only passively viewed, regardless of monitoring latency. Thus, passive object viewing does not lead to significant phonological activation. These results suggest that attentional enhancement is a precondition for obtaining phonological activation from concepts.

In the passive viewing condition of Roelofs et al. (2007), participants may have paid some attention to the pictured object, but apparently not long enough to induce phonological activation. To assess how long attention needs to be sustained, gaze durations were measured by Roelofs (2007). As mentioned earlier, past research on spoken word planning has shown that there is a close link between the duration of word planning and gaze shifts in naming performance (e.g., Griffin, 2004; Korvorst et al., 2006; Meyer et al., 2003). For example, when participants are asked to name two spatially separated objects (e.g., one to the left and the other to the right of a computer screen), they look longer at first-to-be-named objects with disyllabic names (e.g., *lion*) than with monosyllabic names (e.g., *cat*) even when the object recognition times are the same (Meyer et al., 2003). The effect of the phonological length suggests that the shift of gaze from one object to the other is initiated only after the phonological form of the name for the object has been planned sufficiently and the corresponding articulatory program is available. The phonology-dependent gaze shifts may promote naming speed and accuracy by preventing interference from the other object name. Moreover, the phonology-dependent gaze shift may diminish resource demand. Articulating a word such as "cat" or "lion" can easily take half a second or more. If gaze shifts are initiated after identifying the first object, the planning of the name for the second object may be completed well before articulation of the name for the first object has been finished. This means that the second vocal response needs to be buffered for a relatively long time. By starting perception of the second object when planning the first object name is completed sufficiently, the use of buffering resources can be limited.

However, the phonology-dependent gaze shifts are also obtained when the second naming response is replaced by a manual response to a left- or right-pointing arrow (Roelofs, 2007). That is, gaze shifts still depend on phonological encoding when participants name an object and manually indicate the direction of an arrow. This finding suggests that the avoidance of response buffering and the prevention of interference from the second response are not the only reasons for a phonology-dependent gaze shift. Rather, some aspect of spoken word planning itself would appear to be the critical factor. If attentional enhancements are required until the word has been planned far enough, this would explains why attention, indexed by eye gazes, is sustained to word planning until the phonological form is planned. This should hold regardless of the need for response buffering and the prevention of interference, as empirically observed (Roelofs, 2007). The results of the present experiments agree with these observations.

Evidence suggests that the allocation of attention to task performance is not fixed but strategically determined (cf. Kahneman, 1973; Meyer & Kieras, 1997a, 1997b). Attention seems to be sustained to a task just as long as is needed to achieve acceptable levels of speed and accuracy (e.g., Roelofs, 2007). Experiments by Roelofs (2008b) suggest that whether participants sustain attention to word planning until the completion of phonological encoding may depend on the nature of the secondary task. When participants name pictured objects (primary task) and manually respond to arrows or tones (secondary task), phonological encoding for word production delays the manual responses to the arrows but not to the tones. This suggests that participants shift attention earlier to the tones than to the arrows, presumably because vocal response planning hampers auditory perception. Consequently, the tone task needs to be protected against interference from speech planning. This might be achieved through attentional enhancement of the processing of the tones. However, there was a cost to the earlier shifts of attention to the tones, namely an increase in object naming errors. Reynold and Besner (2006) presented evidence from dual-task performance that generating a phonological code from print in reading aloud also requires attention.

To conclude, chronometric evidence on naming performance suggests that spoken word planning requires some attention. Moreover, it seems that attention may to some degree flexibly be allocated to word planning to promote word planning speed and accuracy. The results of the present Experiments 1 and 2 support the assumption that naming performance requires attention and that the attentional demand is reflected in the gaze durations. Moreover, the results of the experiments suggest that the attentional demand of naming performance may be reduced by limiting the attribute exposure duration.

Conclusion

The present experiments demonstrated that relative to color-word display throughout a trial, removing the color attribute diminishes Stroop interference, as well as facilitation effects on color naming RTs, whereas removing the complete Stroop stimulus diminishes interference only. Color attribute as well as complete stimulus removal reduced the latency of gaze shifting, which suggests decreased rather than increased attentional demand. These results provide evidence that reduced exposure duration contributes to attribute naming performance by diminishing the extent to which irrelevant attributes are processed, which diminishes attentional demand.

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