Facultad de Psicología
UNIVERSIDAD DE LA REPÚBLICA

CIBPsi
CENTRO DE INVESTIGACIÓN BÁSICA EN PSICOLOGÍA

Attentional Capture by Color

UNDERGRADUATE THESIS

Degree in Psychology

Modality: scientific paper

November 30th, 2017 - Montevideo, Uruguay

STUDENT: Germán Cipriani Hernández

TUTOR: PhD. Alejandra Carboni

CO-TUTOR: PhD. Dominique Kessel

REVISER: Mg. Camila Zugarramurdi

ABSTRACT:

In human attention, cognitive control plays a central role. This process involves our capacity to monitor conflicts between stimuli and the resolution of this conflict. The Stroop task, which has widely been studied, allows to measure the semantic conflict (Stroop effect) generated by the meaning of a color word and its printed ink (e.g. “RED” printed in green) when participants are asked to name the ink. However, along with semantic processes, this task also involves feature-based attention to color (FBAC), i.e., our capacity to pay attention to color enhancing its representation throughout the visual field, which still remains unexplored in relation to the Stroop effect. Therefore, the aim of this study is to assess color conflict by presenting color distractors during the Stroop task. To this end, 51 volunteers performed a modified Stroop task, where an uninformative and peripheric color distractor was shown together with the color word. Reaction times and error rates were measured, and three variables were manipulated: the congruency between the color word and its ink, the congruency between the ink color of the word and the distractor, and the stimulus onset asynchrony between both stimuli. Reaction times and error rates analyses showed that the Stroop effect was successfully replicated. No evidence of a modulation of the Stroop effect by color distractors was found. However, an attentional capture effect related to FBAC was found for the early exposure to color distractors previously to the color word onset. Congruent color circles with the color word ink produced a facilitatory FBAC effect on reaction times, and incongruent ones produced an interference FBAC effect. This study shows for the first time the influence of short-latency FBAC to color distractors on color targets independently of spatial attention.

KEYWORDS: feature-based attention, cognitive control, Stroop.

1. INTRODUCTION

Human attention is a cognitive process that serves different functions: maintenance of an alert state, direction of voluntary and involuntary perceptive resources toward different stimuli, selection of relevant sensory information, and focus on control and task performance (Posner & Petersen, 1990, 2012; Posner & Rothbart, 2007; Purves et al., 2008; Raz & Buhle, 2006).

One of the main empirical models in the study of attention was proposed by Michael Posner and Steven Petersen in 1990, and revised in 2012. This neurocognitive model proposes the existence of three attentional networks in the human brain: the alerting, the orienting, and the executive network. The three of them are interconnected and perform different attentional functions. The alerting network allows to increase and maintain response readiness in preparation for impending stimuli, and it also serves to sustain vigilance. The orienting network allows to direct attention. If this orienting of attention is intrinsically generated, it is endogenous, and if it is stimulus-driven, it is exogenous. The last of the three networks is the executive control network (or cognitive control). The brain areas that conform the executive network perform different cognitive processes (Dosenbach et al., 2006, 2008). In this network, the cingulo-opercular system is associated with the prolonged performance maintenance during different cognitive tasks. This system is constituted by different regions: left dorsal anterior cingulate cortex, anterior prefrontal cortex, anterior insula and thalamus. The other system is the fronto-parietal network, which is related to strategy changes during conflict resolution and to the application of adjustments in order to correct cognitive performance. This system is conformed by different areas: dorsolateral prefrontal cortex (DLPFC), dorsal frontal cortex, intraparietal sulcus, and inferior parietal lobe.

The Stroop task (Stroop, 1935) has been widely used to assess executive network functioning (MacLeod & MacDonald, 2000; Raz & Buhle, 2006). In this task, participants are instructed to answer to the ink of a word describing a color (color word) that is shown in the center of the monitor. In the congruent condition the word and the ink color coincide (e.g., “RED” printed in red), in the incongruent condition the word and the ink color are different (e.g., “RED” printed in green), and in the neutral condition the word and the ink are not related (e.g., “BOOK” printed in red). The main findings are that participants respond faster in the congruent condition than in the neutral one (facilitation), and faster in the neutral than in the incongruent one (interference). The difference between the incongruent and congruent conditions is called Stroop effect. Previous studies suggest that reading is a process more automatic than naming the color of the ink of the color word; therefore, when participants are asked to name the ink color of an incongruent stimulus a conflict is produced by the contradictory information (Botvinick & Cohen, 2014; Botvinick et al., 2001; Cohen et al., 1990; MacLeod & MacDonald, 2000). To explain the Stroop effect, Cohen et al. (1990) developed a parallel distributed processing (PDP) model. In this model three main types of units are represented: stimulus feature units of the ink color and the color word; specific response units of each ink color; and task control units. The connection between color word features and responses are strengthened by the experience of reading. This model postulates that, in the incongruent condition, two different colors activate different stimulus feature units (e.g., “RED” printed in green), and then a conflict is generated by the activation of two different response units (e.g., red and green). The conflict is resolved by task control units that activate those ink color units, which are the relevant ones to the task. In congruence with this PDP model, imaging evidence reveals that the anterior cingulate cortex (ACC) is the locus of the Stroop conflict detection, and that this brain region recruits the DLPFC to solve the conflict and answer correctly (Botvinick et al., 2004; Kerns et al., 2004; MacDonald et al., 2000).

In the Stroop task, participants need to focus their attention on the ink color of the word. The process of directing visual attention to specific colors is called feature-based attention to color (FBAC). FBAC is a mechanism that allows to enhance color representation throughout the visual field (Maunsell & Treue, 2006; Saenz et al., 2002, 2003; Zhang & Luck, 2009). Evidence from spatial attention paradigms also reveals the existence of a FBAC facilitatory effect to color targets after the exposure to uninformative color cues (Ansorge & Becker, 2014; Folk et al., 1992, 1994, 2010; Harris et al., 2015). Some studies have examined the influence of irrelevant information on the Stroop effect from a semantic point of view, showing that naming the color ink of a color word in the Stroop task is slower when the color to be named was inhibited in the previous trial than when it was not (Dalrymple-Alford & Budayr, 1966; Egner & Hirsch, 2005; Neil, 1977). This negative priming effect reveals that semantic unrelated information can influence future color processing. However, there are no studies that have analyzed the effect of uninformative color cues or color distractors on color naming during the Stroop conflict from a perspective of FBAC.

Therefore, the aim of this experiment was to assess the effect of color distractors on the cognitive conflict generated during the Stroop task. To this end, we presented uninformative peripheral color distractor circles during a Stroop task, while behavioral measures (reaction times and error rates) were recorded. The congruency between the color circle and the ink color of the color word was manipulated. According to the PDP model of information processing in the Stroop task that was mentioned above (Botvinick & Cohen, 2014; Botvinick et al., 2001; Cohen et al., 1990), we expected that the addition of an incongruent stimulus feature unit due to incongruent circles would increase the Stroop effect recruiting more top-down control. On the contrary, we expected a decrease of the Stroop effect thanks to the addition of a congruent stimulus feature unit due to congruent circles.

Stimulus onset asynchrony (SOA) between the circle and the color word was manipulated between -200 and +200 ms, based on previous evidence. Specifically, former studies analyzing the influence of irrelevant colored elements on the processing of color targets had described significant effects when the distractors presented preceded the target (Ansorge & Becker, 2014; Folk et al., 1992, 1994; Harris et al., 2015). Additionally, in several studies employing the Stroop task the color word was separated into two stimuli, a color word that was not painted and a color patch (Appelbaum et al., 2009, 2012, 2014; Glaser & Glaser, 1982; Roelofs, 2010). In these tasks, participants had to answer to the color patch and to ignore the uninformative color word. The general finding was that the Stroop effect was maximal when word and patch were shown at the same time; however, when the word appeared before the color patch, the Stroop effect still remained significant until -400 ms, and it also remained significant when the word appeared after the color patch but not beyond +200 ms. All these studies show that irrelevant color information can modulate the processing of the color word in the Stroop task, even when not presented at the same time.

2. METHODS

Participants

Fifty-one volunteers aged 18 to 30 participated in this experiment, 39 females (M = 23 years, SD = 3.5) and 12 males (M = 24 years, SD = 2.8). All participants reported having normal (or corrected-to-normal) vision, not having dyslexia or color blindness, and were not consuming psychotropic drugs at the moment of the study. Participants were recruited from a pool of volunteers, who completed an online form published in social networks related to the university. All of them participated voluntarily, after providing their informed consent according to the Declaration of Helsinki. They received a non-monetary compensation for their participation. The experimental sessions were conducted in the Centro de Investigación Básica en Psicología (CIBPsi, Facultad de Psicología - Universidad de la República). This experiment was approved by the Ethical Committee of the psychology school.

Stimuli and procedure

Participants performed a modified version of the Stroop task (programmed in PsychoPy2 v.1.83.04; Pierce, 2007, 2008) designed to assess the effect of color distractors on cognitive control. Subjects reported the color of the ink of a word (target) that appeared at the center of the screen **(Figure 1)**. The congruence between the color word and its ink was manipulated as follows: in the congruent condition both colors were equal (e.g. ¨RED¨ printed in red), in the incongruent condition the colors were different (e.g. ¨GREEN¨ printed in red), and in the neutral condition the word was not related to the color (e.g. ¨BOOK¨ printed in red). Along with the target, a colored circle was displayed as a distractor. Stimulus onset asynchrony (SOA) between the circle and the target was manipulated, the circle appeared: 200 ms before (-200), at the same time (0) or 200 ms after the onset of the target (+200). These SOAs were selected based on previous studies that explored the influence of irrelevant information on the color naming process at different latencies (Appelbaum et al., 2009, 2012, 2014). The -200 SOA was specifically chosen to avoid the voluntary (endogenous) orienting of attention to the circle (Carrasco, 2011). The congruence between the color of the circle and the ink of the word was manipulated as well, it was: congruent if both colors were the same, incongruent if both colors were different but the color of the circle was one of the three other possible options, and neutral if the circle was grey. A total of 972 trials were presented in fully random order, with 36 trials per condition (27 conditions: 3 word conditions x 3 circle conditions x 3 SOAs). Every 4.6 min (aprox.) there was a self-controlled break (6 in total), in which the participants were told to rest until they were ready to continue. Each experimental task lasted approximately 45 minutes (including pauses). Before the task, each participant performed 87 practice trials that were similar to those of the experimental task.

Each trial began with the presentation of a fixation cross at the center of the screen for 1100 ms. Second, depending on the SOA condition, the circle or the target appeared. The circle and the word remained on the screen for 150 ms and 350 ms, respectively. The trial ended when a key was pressed. Four ink colors were used to assure participants had a large Stroop effect (Brink & McDowd, 1999). The ink of the word was red, blue, yellow or green; and the correct keys were ¨s¨,¨d¨,¨k¨ and ¨l¨, respectively. The circle colors were the same with the addition of grey for the neutral distractor condition. Participants used their left middle and index fingers to press the ¨s¨ and ¨d¨ keys on the keyboard, and their right index and middle fingers to press ¨k¨ and ¨l¨. Spanish words were used in the color word conditions: ROJO (red), AZUL (blue), AMARILLO (yellow) and VERDE (green) for congruent and incongruent; PERFUME (perfume), TAZA (cup) and LIBRO (book) for neutral. The circle had a width of 3 mm, and it was presented on the screen in the perifovea of the retina at 9 visual angles of ratio from the center of the fovea (Strasburger et al., 2011). The word had a mean of 3.2 cm of ratio (3.7°), and its minimum and maximum length of ratio were 2.4 cm (2.7°) and 4.7 cm (5.3°), respectively.

Written and oral instructions were given to participants before the practice trials. Volunteers were tested in a dark room and were instructed to pay attention only to the ink color of the words that appeared on the monitor. Participants were sitted at a distance of 50 cm from the monitor with their chin on a chinstrap and their forehead on a head support; they were also told to respond as quickly and accurately as possible. They were instructed to maintain fixation on the white cross at the centre of the screen all the time.

Data Analysis

Data and statistical analysis were programmed in RStudio (Team, R, 2015). Reaction times (RT) and error rates (ER) were analyzed as measures of speed and accuracy, respectively. As in a previous Stroop task study (Dupuis & Berent, 2015), outliers were defined per participant as responses faster than 200 ms and slower than the participant's mean plus 2.5 standard deviations. ER were calculated excluding outliers. After outlier extraction (2.2% of data), means and standard deviations per condition were recalculated for each participant. For statistical analyses, RT were normalized using the inverse function (Whelan, 2008) and then multiplied by -1 to make RT and normalized RT to have the same direction. After RT normalization, means and standard deviations were recalculated. **Table 1** and **Figure 2** show the original values of RT and ER (for facilitating interpretation) for the 27 experimental conditions.

Type III repeated-measures ANOVAs were performed on normalized RT and ER. The Stroop effect and its sub-effects of Interference and Facilitation were analyzed separately. ANOVA results are shown in **Table 2**. The Mauchly's sphericity test was performed on each ANOVA to test the assumption of equality of variance. When sphericity was rejected, the Greenhouse-Geisser correction was applied. Post hoc comparisons were performed to determine the significance of pairwise contrasts using the Bonferroni correction procedure. Effect sizes were computed using the eta-squared and partial eta-square methods. All analyses were carried out using RStudio software.

3. RESULTS

Reaction Times

Response time data was analyzed through a 3 x 3 x 3 repeated-measures ANOVA (*SOA, circle, color word*). The *color word* main effect was significant [$F_{(2,100)} = 178$, $p < .001$, $\eta_p^2 = .78$]. Post hoc comparisons demonstrated that the Stroop effect (incongruent - congruent) [$p < .001$] and its sub-effects of Interference (incongruent - neutral) [$p < .001$] and Facilitation (neutral - congruent) [$p < .001$] were significant **(Figure 3)**.

The main effect of *SOA* was also significant [$F_{(2,100)} = 128.7$, $p < .001$, $\eta_p^2 = .72$]. Post hoc comparisons showed that participants answered faster for the -200 SOA (690 ms) than for the SOAs of 0 (730 ms) [$p < .001$] and +200 (743 ms) [$p < .001$], and that they were slower for the +200 SOA than for the 0 SOA [$p < .001$] **(Figure 4)**.

The interaction *SOA* x *circle* was significant as well [$F_{(4,200)} = 112$, $p < .001$, $\eta_p^2 = .69$] **(Figure 5)**. The post hoc comparisons showed that, in the -200 SOA, participants answered faster for congruent circles (639 ms) than for neutral (692 ms) [$p < .001$] and incongruent (739 ms) circles [$p < .001$], and faster for neutral than incongruent circles [$p < .001$]. This difference between congruent and incongruent circles reflects an attentional capture effect due to color distractors. In the +200 SOA, the incongruent (752 ms) circle was also related to slower responses than the congruent circle (731 ms) [$p = .001$], i.e., the attentional capture was also significant. To explore whether these attentional capture effects were significantly different between SOAs, the difference between congruent and incongruent circles was submitted to one-way repeated measures ANOVA with *SOA* (3) as factor. The main effect of *SOA* was significant [$F_{(2,100)} = 186$, $p < .001$, $\eta_p^2 = .79$]. Post hoc comparisons showed that the attentional capture for the -200 SOA was significantly larger than for the 0 [$p < .001$] and +200 SOA [$p < .001$].

Error Rates

ER were analyzed through a 3 x 3 x 3 repeated-measures ANOVA (*SOA, circle, color word*). The effect of *color word* was significant [$F_{(2,100)} = 10$, $p < .001$, $\eta_p^2 = .16$], and the post hoc t-tests revealed the Stroop (1.1%) [$p < .001$] and Interference (1%) [$p < .001$] effects **(Figure 3)**. The main effect of *SOA* [$F_{(2,100)} = 4$, $p = .016$, $\eta_p^2 = .08$] and its post hoc comparisons showed a significant difference between -200 (4.8 %) and 0 (4.2 %) [$p = .016$] **(Figure 4)**.

Stroop Effect (incongruent - congruent)

The Stroop effect on reaction times was submitted to a 3 x 3 repeated-measures ANOVA (*SOA, circle*). The main effect of *SOA* was significant [$F_{(2,100)} = 4$, $p = .027$, $\eta_p^2 = .07$], and post hoc comparisons reflected that the Stroop effect was larger for the -200 SOA (89 ms) than for the +200 (82 ms) SOA [$p = .015$] **(Figure 7)**. A significant effect of circle was found on error rates [$F_{(2,100)} = 5$, $p < .001$, $\eta_p^2 = .09$], but pairwise comparisons did not reach significance.

Interference (inc. - neu. color word) and Facilitation (neu. - cong. color word)

The ER interference effect was analyzed in a 3 x 3 ANOVA (*SOA, circle*). The main effect of *SOA* was found [$F_{(2,100)} = 3$, $p = .046$, $\eta_p^2 = .06$], but comparisons were not significant. No more significant main or interaction effects were found for interference and facilitation.

Attentional Capture (inc. - cong. circle) and Performance

To understand the relation between attentional capture and performance, we tested whether the RT results reflecting attentional capture for the SOAs of -200 and +200 were correlated with mean normalized reaction times and error rates. Attentional capture for the -200 SOA was negatively correlated with normalized RT [$r_{(48)} = -.79$, $p < .01$], and positively correlated with ER [$r_{(48)} = .33$, $p = .02$] **(Figure 8)**. One subject was excluded from all the correlation analyses because his ER was 5.7 SD above the mean.

Speed-Accuracy Tradeoff

The correlation pattern between attentional capture and performance measures found above might be explained by a negative correlation between RT and ER. To test this hypothesis, Pearson's correlation was tested between ER and normalized mean RT (-1/RT). There was a significant negative relation between the two variables [$r_{(48)} = -.29$, $p = .04$].

4. DISCUSSION

In a modified version of the Stroop task, this experiment tested for the first time the effect of color distractors on a cognitive conflict involving color. In previous studies, only the effect of semantic interference on the Stroop effect has been analyzed. We expected that incongruent circles would increase cognitive conflict due to the addition of an incongruent stimulus feature unit, which would be reflected in larger reaction times and/ or higher error rates. On the contrary, we expected a decrease of cognitive conflict due to the addition of a congruent stimulus feature unit by congruent circles, visible in reduced reaction times and/ or error rates, compared to the neutral condition.

The results show that the Stroop effect and its facilitation and interference sub-effects were successfully reproduced in this experiment. Consistent with previous research, the facilitation effect was smaller in magnitude than the interference effect (MacLeod & MacDonald, 2000), and was only significantly reflected in reaction times, but not in error rates.

Contrary to our hypothesis, our results do not show any significant modulation of the cognitive control in the Stroop task by uninformative and irrelevant color distractors. Previous data on FBAC pointed to an influence of irrelevant color distractors on the processing of color targets (Ansorge & Becker, 2014; Folk et al., 1992, 1994, 2010; Harris et al., 2015), but in the present study no significant evidence was found supporting the existence of such an effect on the Stroop conflict. We also calculated the difference between the Stroop effect of incongruent and congruent circles for each SOA, in order to assess its magnitude. For the -200 ms SOA the mean difference of Stroop effects was 23 ms (SD = 71), while it was much -but not significantly- smaller for the 0 ms and +200 ms SOA (8 ms (SD = 87), and 7 ms (SD = 88), respectively). This lack of significance might be related to the task design employed in the present study, where trials of the three different SOAs were presented in a fully randomized order. It is possible that the underlying cognitive processes occurring when presenting the color distractor before, during or after the Stroop target differ in such a way that the resulting data should not be part of the same statistical analysis. However, given the mixed and random presentation of trials of the three SOAs, we are not able to compute separate ANOVAs on the three conditions. This issue should be tested in a future study dividing the task into blocks of SOAs.

The Stroop effect was modulated by the SOA between the circle and the word. It was significantly greater (7 ms) for the -200 SOA than the +200 SOA, and it was close to be significantly higher than for the 0 SOA. In another executive function task, a similar result had been found by Fan et al. (2002). In their experiment, the previous exposure to cues with no spatial information in a flanker task increased the flanker effect in contrast to the no-cue condition. The authors interpret this result as an interaction of the alerting and executive networks, where low alertness can provide additional time for executive control processes to reduce the attentional conflict on the incongruent condition. In our task the Stroop conflict was higher for the -200 SOA than for the other SOAs, and alertness was lower for the 0 and +200 SOAs than for the -200 SOA, therefore we attribute the same interpretation.

The exposure to color distractors during the -200 ms SOA led to faster reaction times and to higher errors rates than for the 0 ms SOA. This can be interpreted as an alerting effect of the alerting attentional network (Fan et al., 2002, 2005). On the contrary, the +200 ms SOA produced slower responses than the 0 ms SOA reflecting a distractor effect of the circle. These effects are secondary but not less important results of the present study, given that, for the first time, we have described the effect of color distractors independently of spatial attention, employing a FBAC paradigm where colored targets and distractors were presented. Specifically, an attentional capture operates when the distractor is shown 200 ms before target appearance but not when both stimuli are presented at the same time. This attentional capture effect was conformed by two sub-effects. First, a facilitatory effect indicating that color circles that had the same color of the color word ink produced faster responses than neutral circles; second, an interference effect was generated by incongruent color distractors revealing slower reaction times in comparison to neutral circles. Up to now, the existing evidence of attentional capture by color had been originated from spatial paradigms (Ansorge & Becker, 2014; Folk et al., 1992, 1994, 2010; Harris et al., 2015), i.e., describing the capture of spatial attention. In this experiment, peripheral distractors facilitated or interfered with the color processing of the target in the fovea; additionally, participants were told to maintain fixation on the center of the screen during the task, the distractor had no predictive value of the target color, and it was shown on the visual periphery, so there was not purpose on orienting spatial attention to the distractor. Therefore, to our knowledge, this is the first evidence of an attentional capture effect by uninformative color distractors that is independent of spatial attention. We interpret this effect as a FBAC effect caused by the color distractors that was spread out throughout the visual field (Maunsell & Treue, 2006; Saenz et al., 2002, 2003; Zhang & Luck, 2009).

Furthermore, the distractor appearance 200 ms after word onset also produced an attentional capture effect, but this capture was significantly smaller than the -200 SOA capture. A possible interpretation of this finding is that at +200 ms, participants are already processing the ink color, and less attentional resources are available to be captured by the circle. On the contrary, at -200 ms, they are not processing any other stimulus at the moment the circle appears, so all attentional resources are available to be captured.

Finally a linear relation between attentional capture and performance measures was found. Specifically, Pearson's correlations revealed a positive relation between attentional capture and error rates at -200 ms, and an inverse relation with reaction times. Consistent with this finding, reaction times and error rates showed a significant inverse relation. This speed-accuracy tradeoff was consistently reported in previous research (Bogacz et al., 2010; Schouten & Bekker, 1967; Wickelgren, 1977). This result means that the capture of FBAC is maximum when participants prioritize speed over accuracy. This might indicate that participants who postpone their response have more attentional resources in order to deal with the attentional capture effect than those who respond immediately after the capture occurs.

In conclusion, this experiment did not provide any significant evidence of a modulation of cognitive control in a contingent way by color distractors. However, it showed the existence of an attentional capture by color distractors when processing color targets in a Stroop task. This capture is stronger when a color distractor appears before the target than when it appears after the target and increases when participants prioritize speed over accuracy. This is a novel result indicating for the first time an effect of color distractors on color targets in a FBAC paradigm, independently of spatial attention.

5. REFERENCES

Ansorge, U., & Becker, S. I. (2014). Contingent capture in cueing: the role of color search templates and cue-target color relations. *Psychological research, 78*(2), 209-221.

Appelbaum, L. G., Boehler, C. N., Davis, L. A., Won, R. J., & Woldorff, M. G. (2014). The dynamics of proactive and reactive cognitive control processes in the human brain. *Journal of cognitive neuroscience, 26*(5), 1021-1038.

Appelbaum, L. G., Boehler, C. N., Won, R., Davis, L., & Woldorff, M. G. (2012). Strategic allocation of attention reduces temporally predictable stimulus conflict. *Journal of cognitive neuroscience, 24*(9), 1834-1848.

Appelbaum, L. G., Meyerhoff, K. L., & Woldorff, M. G. (2009). Priming and backward influences in the human brain: processing interactions during the stroop interference effect. *Cerebral Cortex, 19*(11), 2508-2521.

Bogacz, R., Wagenmakers, E. J., Forstmann, B. U., & Nieuwenhuis, S. (2010). The neural basis of the speed–accuracy tradeoff. *Trends in neurosciences, 33*(1), 10-16.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological review, 108*(3), 624.

Botvinick, M. M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex: an update. *Trends in cognitive sciences, 8*(12), 539-546.

Botvinick, M. M., & Cohen, J. D. (2014). The computational and neural basis of cognitive control: charted territory and new frontiers. *Cognitive science, 38*(6), 1249-1285.

Brink, J. M., & McDowd, J. M. (1999). Aging and selective attention: an issue of complexity or multiple mechanisms?. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 54*(1), P30-P33.

Carrasco, M. (2011). Visual attention: The past 25 years. *Vision research, 51*(13), 1484-1525.

Cohen, J. D., Dunbar, K., & McClelland, J. L. (1990). On the control of automatic processes: a parallel distributed processing account of the Stroop effect. *Psychological review, 97*(3), 332.

Dalrymple-Alford, E. C., & Budayr, B. (1966). Examination of some aspects of the Stroop color-word test. *Perceptual and motor skills, 23*(3_suppl), 1211-1214.

Dosenbach, N. U., Visscher, K. M., Palmer, E. D., Miezin, F. M., Wenger, K. K., Kang, H. C., ... & Petersen, S. E. (2006). A core system for the implementation of task sets. *Neuron*, *50*(5), 799-812.

Dosenbach, N. U., Fair, D. A., Cohen, A. L., Schlaggar, B. L., & Petersen, S. E. (2008). A dual-networks architecture of top-down control. *Trends in cognitive sciences*, *12*(3), 99-105.

Dupuis, A., & Berent, I. (2015). Signs are symbols: evidence from the Stroop task. *Language, Cognition and Neuroscience, 30*(10), 1339-13

Egner, T., & Hirsch, J. (2005). Where memory meets attention: neural substrates of negative priming. *Journal of Cognitive Neuroscience, 17*(11), 1774-1784.

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of cognitive neuroscience, 14*(3), 340-347.

Fan, J., McCandliss, B. D., Fossella, J., Flombaum, J. I., & Posner, M. I. (2005). The activation of attentional networks. *Neuroimage, 26*(2), 471-479.

Folk, C. L., & Remington, R. (2010). A critical evaluation of the disengagement hypothesis. *Acta Psychologica, 135*(2), 103-105.

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology Human Perception and Performance, 18*, 1030-1030.

Folk, C. L., Remington, R. W., & Wright, J. H. (1994). The structure of attentional control: Contingent attentional capture by apparent motion, abrupt onset, and color. *Journal of Experimental Psychology-Human Perception and Performance, 20*(2), 317-329.

Glaser, M. O., & Glaser, W. R. (1982). Time course analysis of the Stroop phenomenon. *Journal of Experimental Psychology: Human Perception and Performance, 8*(6), 875.

Harris, A. M., Becker, S. I., & Remington, R. W. (2015). Capture by colour: Evidence for dimension-specific singleton capture. *Attention, Perception, & Psychophysics, 77*(7), 2305-2321.

Kerns, J. G., Cohen, J. D., MacDonald, A. W., Cho, R. Y., Stenger, V. A., & Carter, C. S. (2004). Anterior cingulate conflict monitoring and adjustments in control. *Science, 303*(5660), 1023-1026.

MacDonald, A. W., Cohen, J. D., Stenger, V. A., & Carter, C. S. (2000). Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. *Science, 288*(5472), 1835-1838.

MacLeod, C. M., & MacDonald, P. A. (2000). Interdimensional interference in the Stroop effect: Uncovering the cognitive and neural anatomy of attention. *Trends in cognitive sciences*, *4*(10), 383-391.

Maunsell, J. H., & Treue, S. (2006). Feature-based attention in visual cortex. *Trends in neurosciences, 29*(6), 317-322.

Neill, W. T. (1977). Inhibitory and facilitatory processes in selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 3*(3), 444.

Peirce, J. W. (2007). PsychoPy—psychophysics software in Python. *Journal of neuroscience methods*, *162*(1), 8-13.

Peirce, J. W. (2008). Generating stimuli for neuroscience using PsychoPy. *Frontiers in neuroinformatics*, *2*.

Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual review of neuroscience*, *35*, 73-89.

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual review of neuroscience*, *13*(1), 25-42.

Posner, M. I., & Rothbart, M. K. (2007). Research on attention networks as a model for the integration of psychological science. *Annu. Rev. Psychol., 58*, 1-23.

Purves, D., Cabeza, R., Huettel, S. A., LaBar, K. S., Platt, M. L., Woldorff, M. G., & Brannon, E. M. (2008). Principles of attention. In *Cognitive Neuroscience.* Sunderland: Sinauer

Associates, Inc.

Raz, A., & Buhle, J. (2006). Typologies of attentional networks. *Nature Reviews Neuroscience, 7*(5).

Roelofs, A. (2010). Attention, temporal predictability, and the time course of context effects in naming performance. *Acta psychologica, 133*(2), 146-153.

Saenz, M., Buracas, G. T., & Boynton, G. M. (2002). Global effects of feature-based attention in human visual cortex. *Nature neuroscience, 5*(7), 631-632.

Sàenz, M., Buraĉas, G. T., & Boynton, G. M. (2003). Global feature-based attention for motion and color. *Vision research, 43*(6), 629-637.

Schouten, J. F., & Bekker, J. A. M. (1967). Reaction time and accuracy. *Acta psychologica, 27*, 143-153.

Strasburger, H., Rentschler, I., & Jüttner, M. (2011). Peripheral vision and pattern recognition: A review. *Journal of vision, 11*(5), 13-13.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of experimental Psychology, 18*(6), 643.

Team, R. (2015). RStudio: integrated development for R. RStudio, Inc., Boston, MA URL http://www.rstudio.com.

Whelan, R. (2008). Effective analysis of reaction time data. *The Psychological Record, 58*(3), 475.

Wickelgren, W. A. (1977). Speed-accuracy tradeoff and information processing dynamics. *Acta psychologica, 41*(1), 67-85.

Zhang, W., & Luck, S. J. (2009). Feature-based attention modulates feedforward visual processing. *Nature neuroscience, 12*(1), 24-25.

6. APPENDIX

Figure 1. Stimulus sequence of the experimental trial. Example of an incongruent trial of each SOA with incongruent color word and circle distractor conditions. The green key (¨I¨) is the correct answer. Stimulus onset asynchrony, SOA. Inter-stimulus interval, ISI. Reaction time, RT.

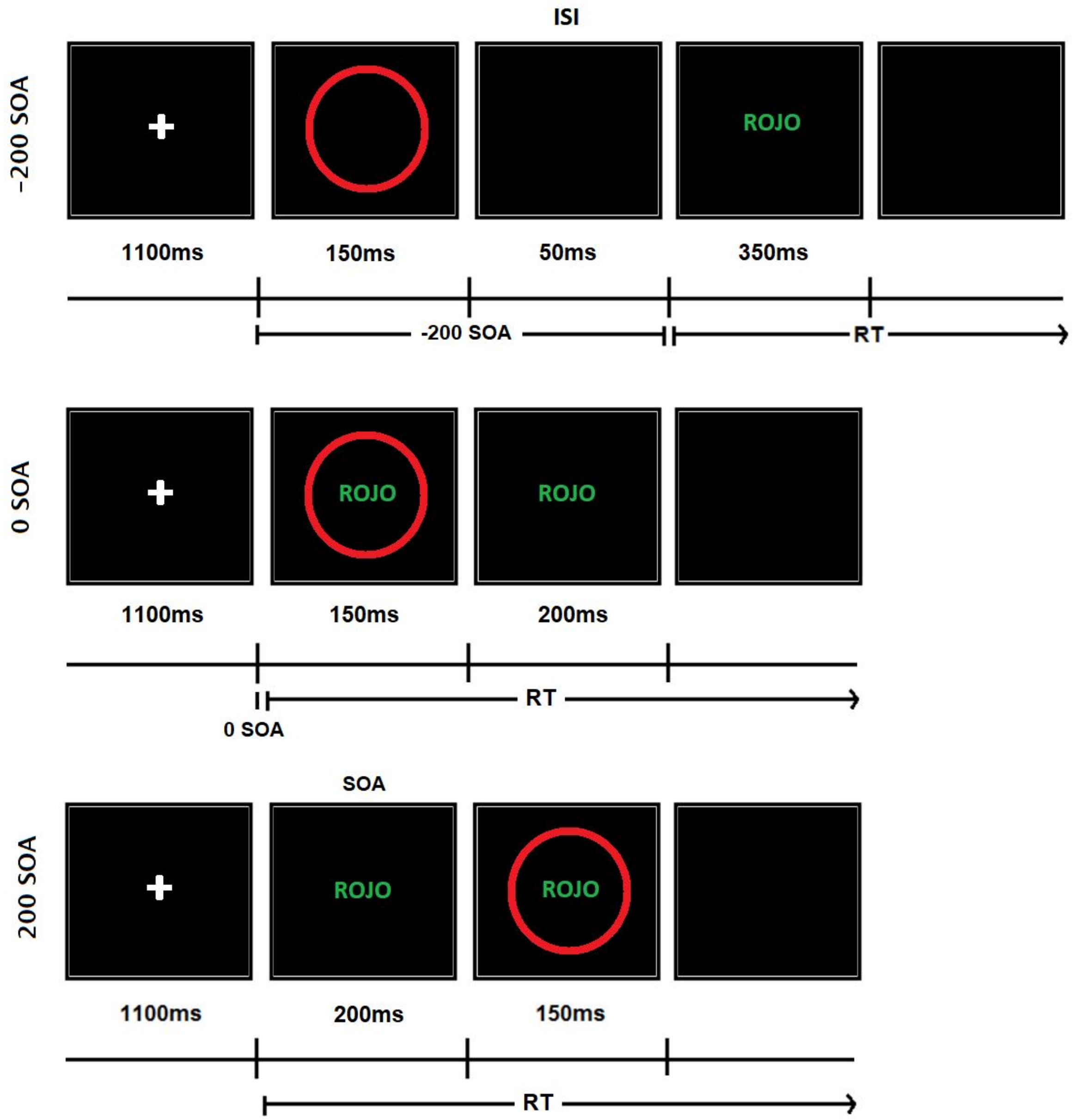
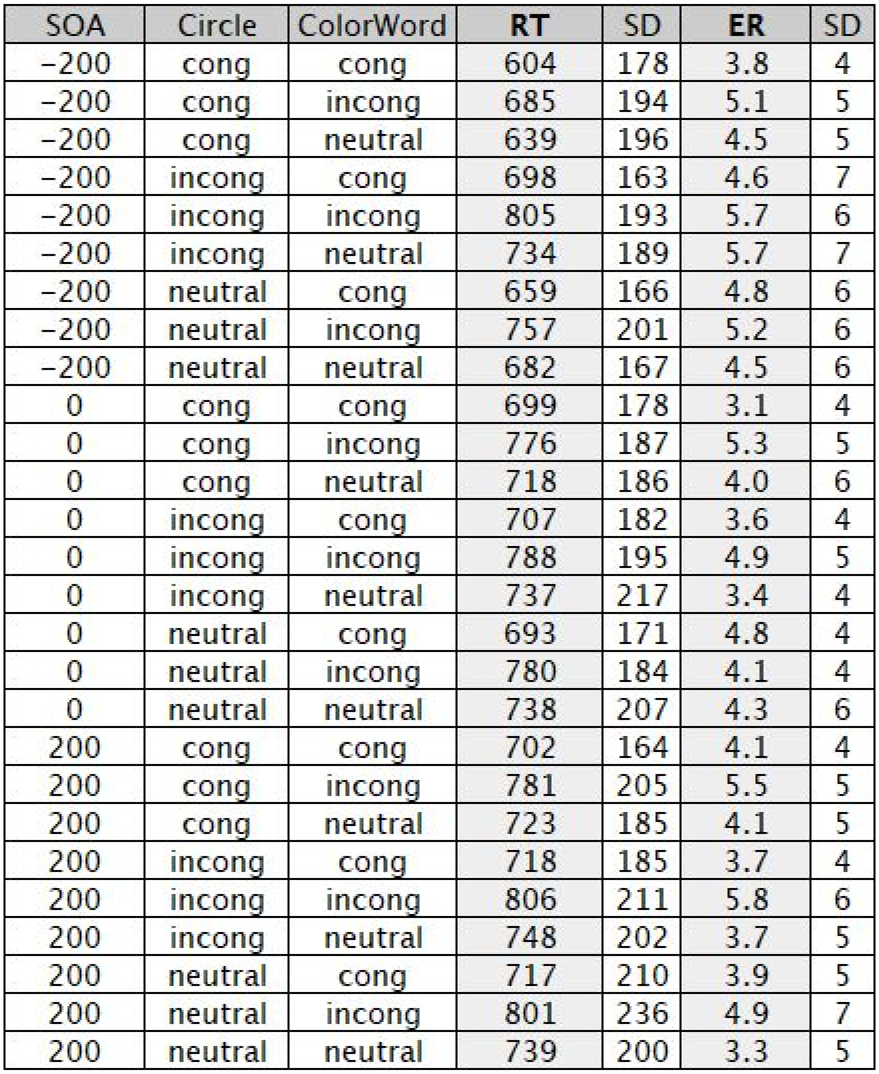


Table 1. Mean reaction times and error rates. Means of reaction times and error rates for the 27 conditions. RT, reaction times, in milliseconds. ER, error rates. Cong, congruent. Incong, incongruent. SD, standard deviation.



SOA	Circle	ColorWord	**RT**	SD	**ER**	SD
−200	cong	cong	604	178	3.8	4
−200	cong	incong	685	194	5.1	5
−200	cong	neutral	639	196	4.5	5
−200	incong	cong	698	163	4.6	7
−200	incong	incong	805	193	5.7	6
−200	incong	neutral	734	189	5.7	7
−200	neutral	cong	659	166	4.8	6
−200	neutral	incong	757	201	5.2	6
−200	neutral	neutral	682	167	4.5	6
0	cong	cong	699	178	3.1	4
0	cong	incong	776	187	5.3	5
0	cong	neutral	718	186	4.0	6
0	incong	cong	707	182	3.6	4
0	incong	incong	788	195	4.9	5
0	incong	neutral	737	217	3.4	4
0	neutral	cong	693	171	4.8	4
0	neutral	incong	780	184	4.1	4
0	neutral	neutral	738	207	4.3	6
200	cong	cong	702	164	4.1	4
200	cong	incong	781	205	5.5	5
200	cong	neutral	723	185	4.1	5
200	incong	cong	718	185	3.7	4
200	incong	incong	806	211	5.8	6
200	incong	neutral	748	202	3.7	5
200	neutral	cong	717	210	3.9	5
200	neutral	incong	801	236	4.9	7
200	neutral	neutral	739	200	3.3	5

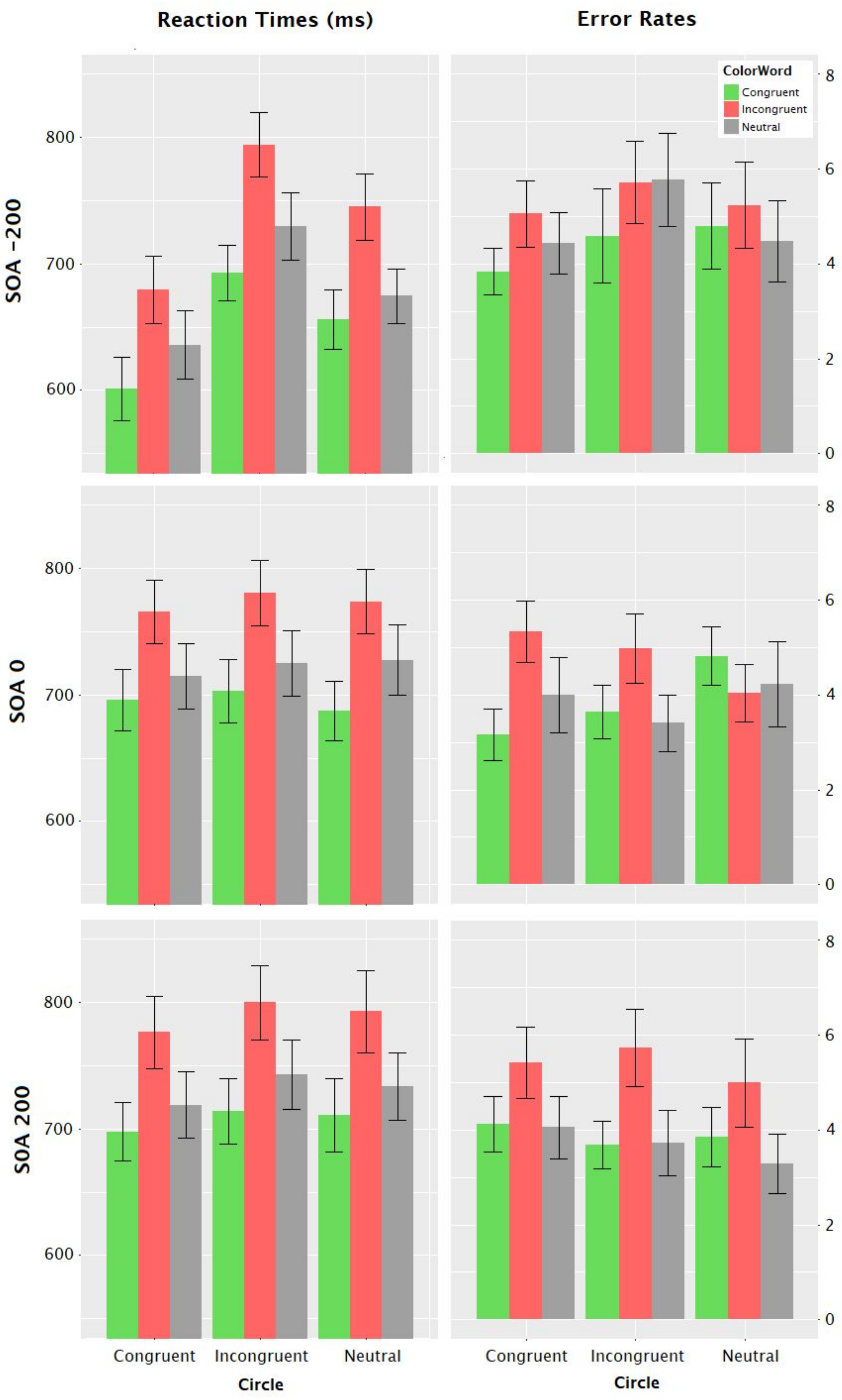
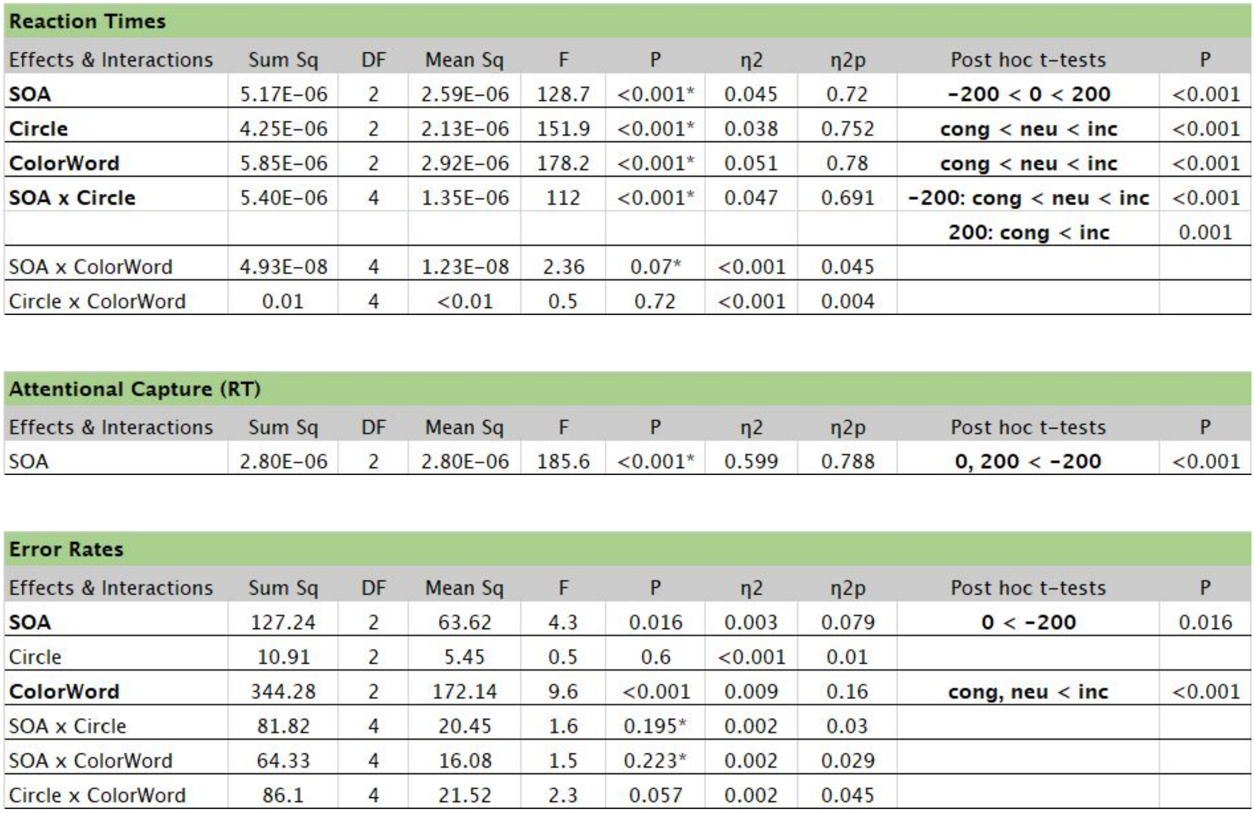


Figure 2. Mean reaction times and error rates. Error bars represent one standard error.

Table 2. ANOVA main effects and interactions. Type III repeated measures analysis of variance were performed on normalized RT, ER, Stroop effect, interference, facilitation and attentional capture. Post hoc t-tests were conducted with Bonferroni adjusted p values for multiple comparisons, only significant results are shown. DF, degrees of freedom. Sum Sq, sum of squares. Mean Sq, mean of squares. F, F-test. P, p value. η2, eta squared. η2p, partial eta squared. (*) Greenhouse-Geisser corrected p values. Significant effects and interactions are shown in bold.



Reaction Times

Effects & Interactions	Sum Sq	DF	Mean Sq	F	P	η2	η2p	Post hoc t-tests	P
SOA	5.17E-06	2	2.59E-06	128.7	<0.001*	0.045	0.72	**-200 < 0 < 200**	<0.001
Circle	4.25E-06	2	2.13E-06	151.9	<0.001*	0.038	0.752	**cong < neu < inc**	<0.001
ColorWord	5.85E-06	2	2.92E-06	178.2	<0.001*	0.051	0.78	**cong < neu < inc**	<0.001
SOA x Circle	5.40E-06	4	1.35E-06	112	<0.001*	0.047	0.691	**-200: cong < neu < inc**	<0.001
								200: cong < inc	0.001
SOA x ColorWord	4.93E-08	4	1.23E-08	2.36	0.07*	<0.001	0.045		
Circle x ColorWord	0.01	4	<0.01	0.5	0.72	<0.001	0.004		

Attentional Capture (RT)

Effects & Interactions	Sum Sq	DF	Mean Sq	F	P	η2	η2p	Post hoc t-tests	P
SOA	2.80E-06	2	2.80E-06	185.6	<0.001*	0.599	0.788	**0, 200 < -200**	<0.001

Error Rates

Effects & Interactions	Sum Sq	DF	Mean Sq	F	P	η2	η2p	Post hoc t-tests	P
SOA	127.24	2	63.62	4.3	0.016	0.003	0.079	**0 < -200**	0.016
Circle	10.91	2	5.45	0.5	0.6	<0.001	0.01		
ColorWord	344.28	2	172.14	9.6	<0.001	0.009	0.16	**cong, neu < inc**	<0.001
SOA x Circle	81.82	4	20.45	1.6	0.195*	0.002	0.03		
SOA x ColorWord	64.33	4	16.08	1.5	0.223*	0.002	0.029		
Circle x ColorWord	86.1	4	21.52	2.3	0.057	0.002	0.045		

Stroop Effect									
Reaction Times									
Effects & Interactions	Sum Sq	DF	Mean Sq	F	P	η2	η2p	Post hoc t-tests	P
SOA	9.20E-08	2	4.60E-08	3.8	0.027	0.013	0.07	**200 < -200**	0.015
Circle	6.36E-09	2	3.18E-09	0.3	0.733	0.001	0.006		
SOA x Circle	2.39E-08	4	5.98E-09	0.3	0.538	0.003	0.011		
Error Rates									
Effects & Interactions	Sum Sq	DF	Mean Sq	F	P	η2	η2p	Post hoc t-tests	P
SOA	32.55	2	16.28	0.6	0.55	0.003	0.012		
Circle	162.61	2	81.31	5.1	0.008	0.013	0.092	-	>0.05
SOA x Circle	115.39	4	28.85	1	0.387	0.01	0.02		

Interference Effect									
Reaction Times									
Effects & Interactions	Sum Sq	DF	Mean Sq	F	P	η2	η2p	Post hoc t-tests	P
SOA	3.06E-08	2	1.53E-08	1.3	0.27	0.005	0.026		
Circle	6.68E-09	2	3.34E-09	0.3	0.755	0.001	0.006		
SOA x Circle	3.61E-08	4	9.02E-09	0.7	0.603	0.006	0.014		
Error Rates									
Effects & Interactions	Sum Sq	DF	Mean Sq	F	P	η2	η2p	Post hoc t-tests	P
SOA	121.92	2	60.96	3.2	0.046	0.01	0.06	-	>0.05
Circle	15.16	2	7.58	0.4	0.691	0.001	0.007		
SOA x Circle	107.39	4	26.85	0.8	0.511	0.009	0.016		

Facilitation Effect									
Reaction Times									
Effects & Interactions	Sum Sq	DF	Mean Sq	F	P	η2	η2p	Post hoc t-tests	P
SOA	2.51E-08	2	1.26E-08	1.7	0.194	0.005	0.032		
Circle	1.46E-10	2	7.30E-11	<0.01	0.992	<0.001	<0.001		
SOA x Circle	8.02E-08	4	2.00E-08	1.8	0.131	0.016	0.035		
Error Rates									
Effects & Interactions	Sum Sq	DF	Mean Sq	F	P	η2	η2p	Post hoc t-tests	P
SOA	38.5	2	19.25	1	0.375	0.004	0.019		
Circle	80.52	2	40.26	2.1	0.13	0.008	0.041		
SOA x Circle	44.37	4	11.09	0.5	0.722	0.005	0.01		

Figure 3. Mean reaction times and error rates per color word condition. Significant differences are represented by horizontal bars. P values: <0.05 (*), <0.01 (**), <0.001 (***). Error bars represent one standard error.

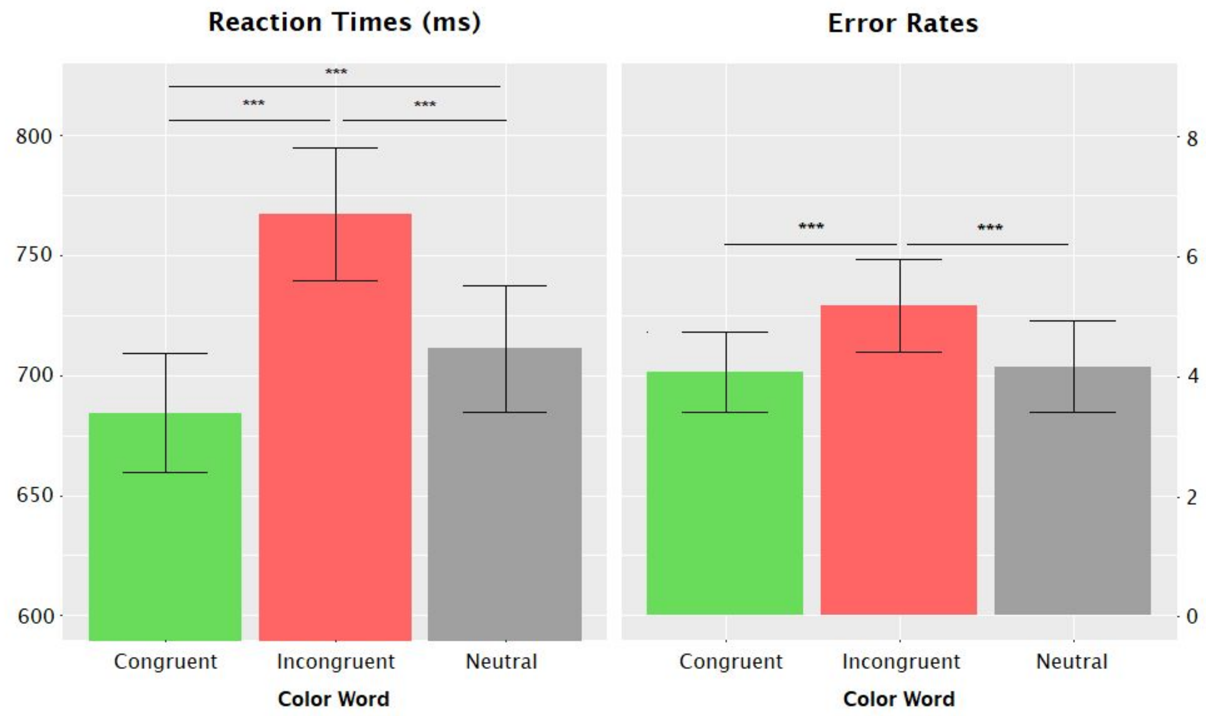


Figure 4. Mean reaction times and error rates per SOA. Significant differences are represented by horizontal bars. P values: <0.05 (*), <0.01 (**), <0.001 (***). Error bars represent one standard error.

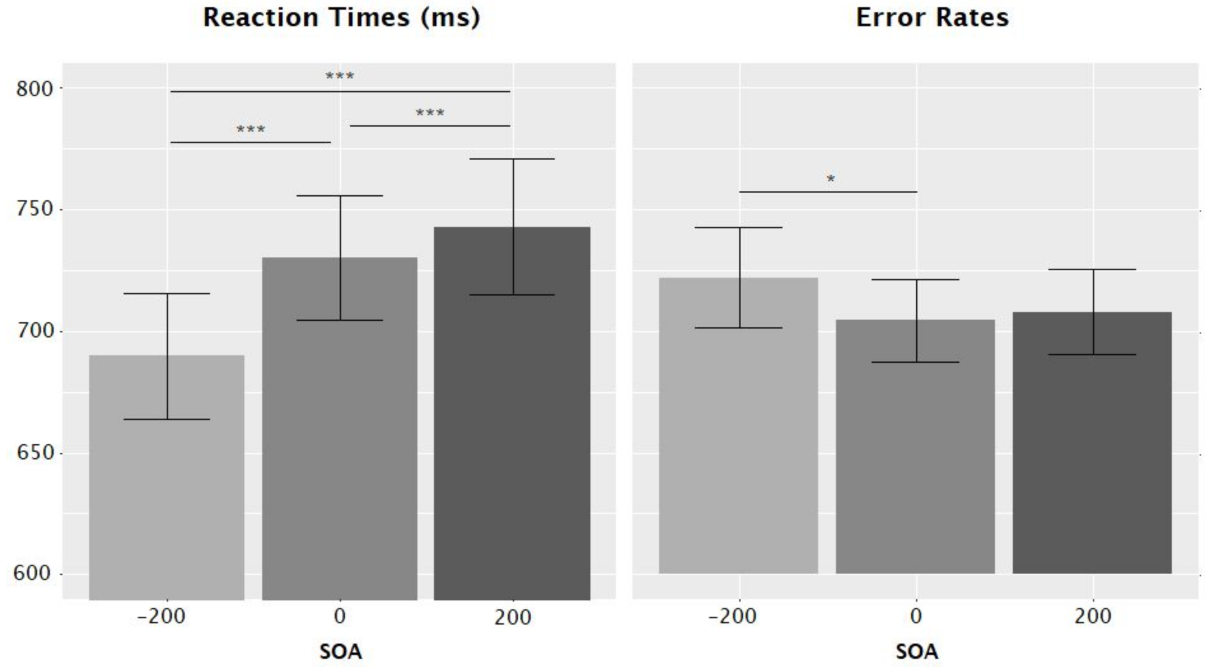


Figure 5. Mean reaction times per circle condition. Significant differences are represented by horizontal bars. P values: <0.05 (*), <0.01 (**), <0.001 (***). Error bars represent one standard error.

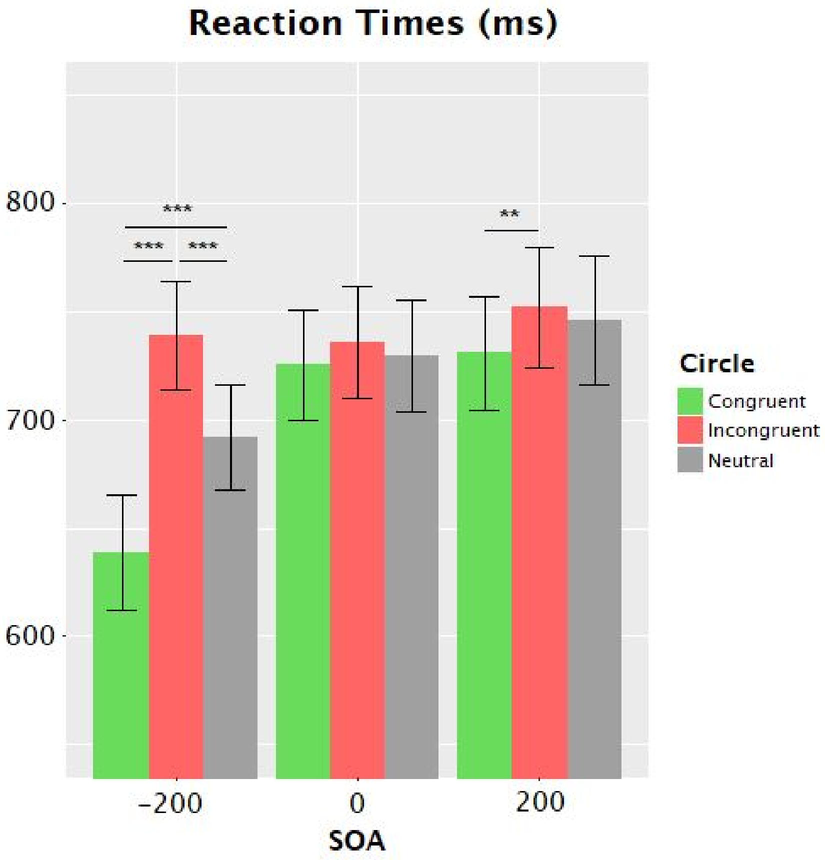


Figure 6. Attentional capture by color distractors. The attentional capture effect reflected in RT for the -200 SOA was significantly greater than for 0 and +200 ms. Significant differences are represented by horizontal bars. P values: <0.05 (*), <0.01 (**), <0.001 (***). Error bars represent one standard error.

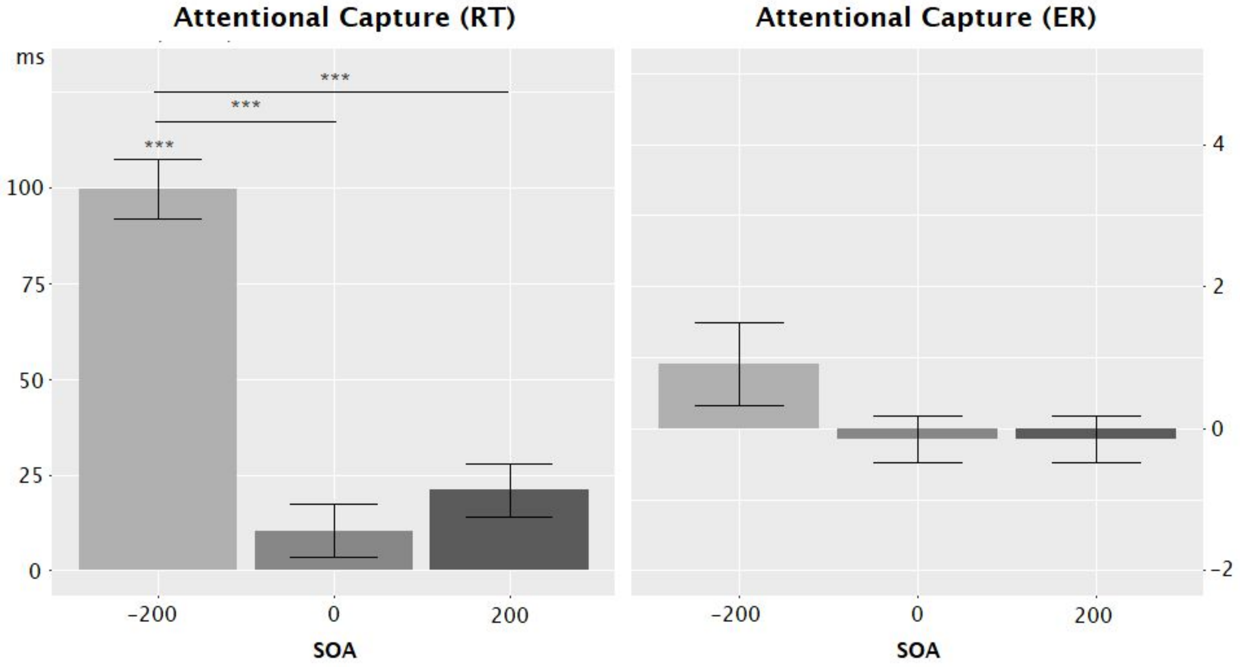


Figure 7. Stroop effect for reaction times per SOA. Significant differences are represented by horizontal bars. P values: <0.05 (*), <0.01 (**), <0.001 (***). Error bars represent one standard error.

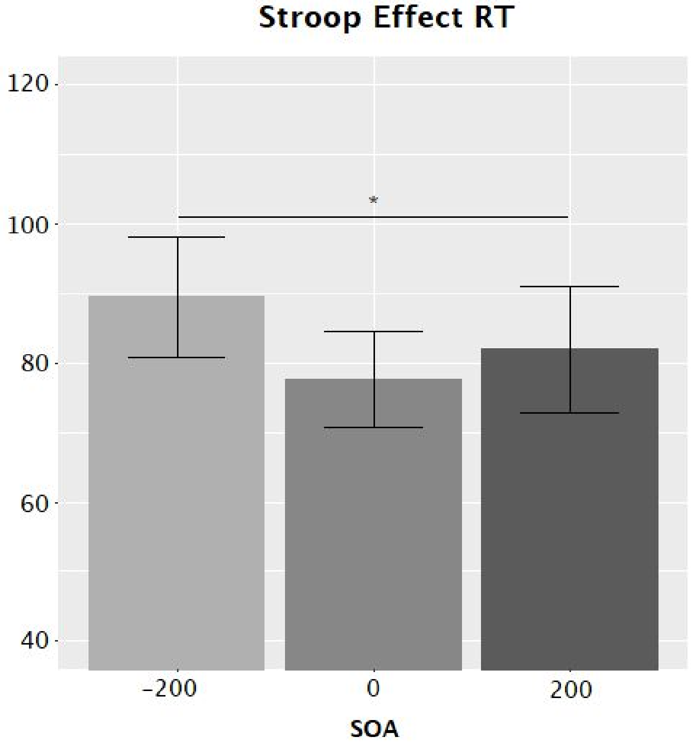
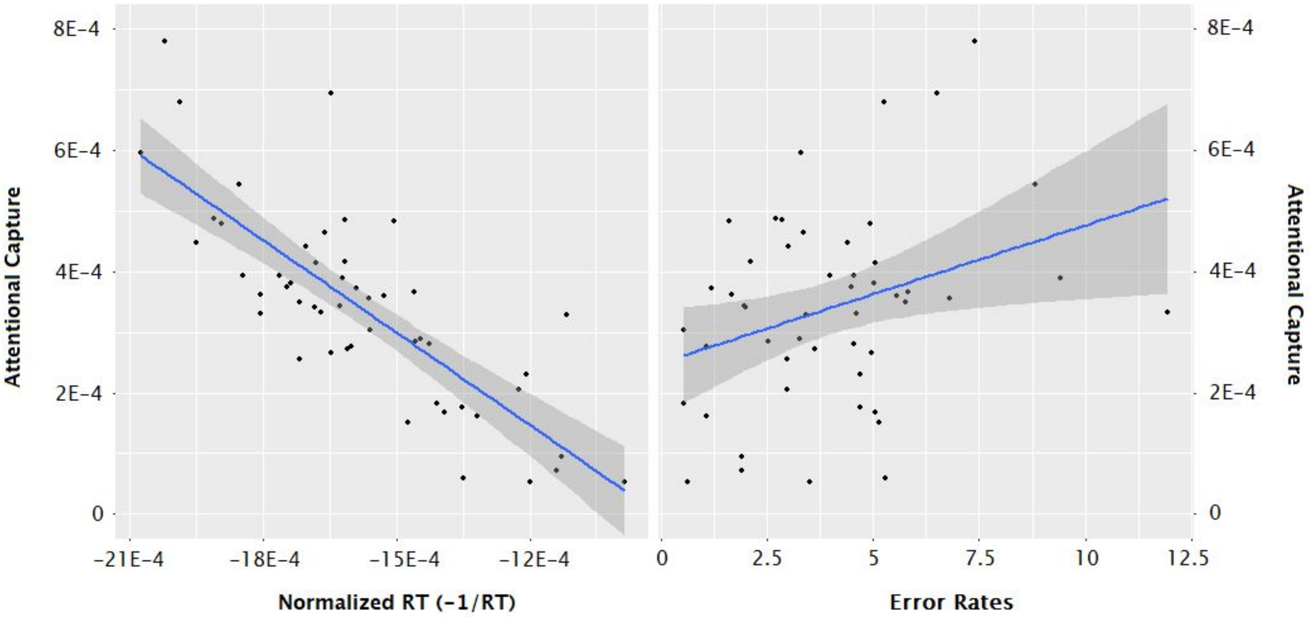


Figure 8. Pearson's correlations between Attentional Capture and Performance for the SOA of -200 ms. On the left, significant negative correlation between normalized reaction times (-1/RT) and the attentional capture for -200 ms [$r_{(48)}$ = -.79, p < .01]. On the right, significant positive correlation between error rate and the attentional capture for -200 ms [$r_{(48)}$ = .33, p = .02]. The shaded areas represents the 95% confidence interval.



7. ACKNOWLEDGEMENTS

This thesis is dedicated to my parents Stella Hernández and Sergio Cipriani, and to my sisters Florencia and Regina. I thank them for all their love and indispensable support. I also want to express gratitude to all the volunteers of the two pilot studies and the experiment, this study could not be possible without their participation. Specifically thanks to: Bruno Guidi, Camila Mateauda, Dasha Egorov, Dinorah de León, Eliana Nicolaisen, Emilia Fló, Emiliano Manacorda, Fabiana Farinasso, Gariné Guidi, Iván Egorov, Karina Cipriani, Leandro Machín, Mariana Sierra, Mateo Arcos, Sabrina Farinasso, Sofía Farinasso, Valentina Paz and Viviana Fontán. This research was carried out thanks to the CIBPsi support. Finally thanks to Dominique, Alejandra and Camila for their corrections and tutorship.