

## **The Stroop-matching task as a tool to study the correspondence effect using images of graspable and non-graspable objects**

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## **Abstract**

The Stroop-matching task is a variation of the Stroop task in which participants have to compare a Stroop stimulus attribute (color or word) to a second stimulus. The Stroop-matching response conflict (SMRC) represents an interference related to the processes involved in selection/execution of manual responses. In the present study we developed a variation of the Stroop-matching task in which the Stroop stimuli were matched to graspable objects (a cup) with intact or broken handles laterally oriented (Experiment 1) or to colored bars laterally presented (Experiment 2). It allowed testing the presence of the correspondence effect for lateralized handles and bars, and its possible influence on SMRC. Two different intervals (100 and 800 ms) were also included to investigate time-modulations in behavioral performance (reaction time and accuracy). Fifty-five volunteers participated in the study. In both experiments, significant SMRC was found, but no interaction occurred between SMRC and correspondence effect, supporting that the hypothesis of different and relatively independent psychological mechanisms is at the basis of each effect. Because significant facilitation for ipsilateral motor responses (correspondence effect) occurred for graspable objects but not for lateralized bars, the attentional shift/spatial coding view was not able to completely explain our data, and therefore, the grasping affordance hypothesis remained as the most plausible explanation. The time course of facilitation observed in the first experiment and by others indicates the importance of further studies to better understand the time dynamic of facilitation/inhibition of motor responses induced by graspable objects.

## Introduction

The human brain enables the processing of complex and varying information coming from an environment by filtering and distinguishing relevant and irrelevant information. In the Stroop task, subjects are required to respond to the surface color of stimuli while ignoring the word. The so-called Stroop effect relies on the behavioral phenomenon that participants spent more time naming the surface color of an incongruent color-word stimulus (e.g., BLUE written in red) than a congruent one (e.g., RED written in red) or a colored bar (Stroop, 1935; MacLeod, 1991). The interference observed in incongruent stimuli is considered a hallmark of the competition between task-relevant and task-irrelevant contingencies. Many studies have shown that the executive attentional system is primarily responsible for the cognitive control that allows the allocation of attentional resources to process relevant stimuli and/or suppress irrelevant ones (Posner & Digirolamo, 1998; MacLeod & MacDonald, 2000; Milham et al., 2001; van Veen & Carter, 2005; Banich, 2009; Diamond, 2013; Friedman & Miyake 2017).

Since the original study by Stroop (1935), countless variations of the paradigm have been created. One of the particular interests to the present study is the Stroop-matching task, first used by Treisman and Fearnley (1969). In this protocol, a congruent or incongruent Stroop stimulus is presented with another stimulus (e.g., a colored bar) and participants had to compare the relevant attributes of both stimuli according to the instructions (e.g., compare the word of the Stroop stimulus with the colored bar). After the pioneer work by Treisman and Fearnley (1969), several studies have explored the Stroop-matching task using different approaches in an attempt to better understand the interferences underlying the Stroop effect (Luo, 1999; Goldfarb & Henik, 2006; Caldas et al., 2012 and 2014; Machado-Pinheiro et al., 2010; David et al., 2011; Dittrich & Stahl, 2017).

In the classical Stroop task, response latencies for incongruent stimuli are longer than those for congruent stimuli – the congruency effect. However, in the Stroop-matching task version adopted by Goldfarb and Henik (2006), an intriguing pattern of results was observed. In their study, a colored bar was presented along with a Stroop stimulus and participants were instructed to match the color of the bar with the word of the Stroop stimulus by pressing two different keys, with the right or left hands, if they were “same” or “different”. They found that manual responses were longer for

congruent trials with “different” responses and for incongruent trials with the “same” response, in relation to congruent trials for the “same” response and incongruent trials for “different” responses. According to the authors, besides performing the comparison required by the task, participants also performed an unnecessary and erroneous comparison between both relevant (word) and irrelevant (color) attributes of the Stroop stimulus. Thus, an erroneous response code “same” was generated when the Stroop stimulus was congruent, and an erroneous response code “different” was generated when the Stroop stimulus was incongruent. When the erroneous response code matched with the correct response code generated by the comparison required in the task, there was no response conflict. In contrast, response conflict arose when different response codes were generated by erroneous and correct matches, causing the activation of both hands in the same trial. Thus, response conflict refers to a conflict that is not related solely to the nature of the Stroop stimulus (congruent or incongruent), but depends on the relationship between the response codes generated in a given trial. This response conflict (hereafter called “Stroop-matching response conflict” - SMRC) has been attributed to the processes involved in response selection/execution (Goldfarb & Henik, 2006), while the classical congruency effect occurs at pre-response level and involves the processes required to encode both Stroop attributes *per se*. In fact, EMG data revealed that these competing activations at response level affect motor performance and increase the frequency of double hand activations in trials with SMRC (Caldas et al., 2012). However, despite confirming that response conflict plays an important role in the Stroop-matching task interference, this does not exclude the joint participation of other mechanisms in the Stroop effect scenario, which remains as focus of debate (Luo, 1999; David et al., 2011; Caldas et al., 2012; Sturz et al., 2013; Green et al., 2016; Dittrich & Stahl 2017).

A crucial aspect of the aforementioned studies is that the comparisons always involved the Stroop stimulus with stimuli centrally presented, not capable – either implicitly or explicitly – to spatially direct attention (to the left or to the right), and/or to elicit lateralized motor responses. In the first experiment, we used a variation of the Stroop-matching task in which participants matched the Stroop stimulus to a graspable object (a central colored cup) with its handle laterally oriented. This protocol implies that the lateralized handle can potentially affect manual responses such as in spatial stimulus-response compatibility tasks. Classically, spatial compatibility effects occur

when the spatial location of the stimulus and the response mapping overlap: manual responses are faster and more accurate when stimulus and response locations correspond (compatible mappings) than when they do not (incompatible mappings) (Nicoletti et al., 1982; Alluisi & Warm, 1990; Proctor & Vu, 2006). This is true even when the target location is irrelevant to the task, as in the Simon task in which target shape or color determines the response mapping (Simon, 1990; for a review, see Hommel, 2011). Concerning graspable objects, the stimulus-response compatibility effect, hereinafter the “correspondence effect”, is due to an overlap between the spatial stimulus properties (e.g., the handle) and response dimensions. Many studies have shown that correspondence effects do exist when handled objects, such as frying pans or cups, were used: behavioral performance was favored for corresponding manual responses (ipsilateral to the handle) than for non-corresponding ones (e.g., Tucker & Ellis, 1998; Cho & Proctor 2010, 2011; Pappas, 2014). The reason for this better performance for corresponding responses is topic of intense debate. Some authors propose that the simple visualization of graspable objects (such as cups, hammers, teapots) recruits motor programs necessary to reach and interact with the object, even in the absence of any motor output requirement (Grafton et al., 1997; Buccino et al., 2009; Cardellicchio et al., 2011) – the “affordance effect”. Thus, some visual properties of an object (a cup’s handle, for example) seem to be particularly salient and capable to generate this facilitation (e.g., Tucker & Ellis 1998; Craighero et al., 1999; Phillips & Ward, 2002; Fischer & Dahl, 2007). We will refer to the facilitation for ipsilateral motor responses observed in graspable objects as the “grasping affordance” hypothesis.

However, besides the grasping affordance view, another interesting possibility is that since the handle renders a cup an asymmetrical object, this asymmetry could make the handle more salient than other parts capturing attention on it. This attentional shift should lead to the generation of a stimulus spatial code responsible for priming (and facilitating) ipsilateral manual responses (e.g., Anderson et al., 2002; Cho & Proctor, 2010; Matheson et al., 2014) – the “attentional shift” view, also reported as the spatial coding view (e.g., Hommel, 1993; Cho & Proctor, 2010, 2011, 2013). Hence, the correspondence effect for graspable objects should represent a special type of Simon effect, the so-called object-based Simon effect (Cho & Proctor 2010, 2011, 2013).

Since the handle-hand correspondence effect arises at a response or hand-object interaction stage, response conflicts analogous to those pointed by Goldfarb and Henik

(2006) can also be proposed as follows: no matter if the ipsilateral facilitation is caused by motor program activation (the grasping affordance view) or by spatial orientation (the attentional shift/spatial coding view), the vision of an object with the handle laterally oriented would facilitate spatially congruent responses and no response conflict would occur. However, when the handle does not coincide with the responding hand, both hands will be activated and therefore, the response conflict will be established - from now on “handle-hand correspondence conflict”.

The first aim of the present study was to confirm the existence of a correspondence effect under the conditions adopted in the first experiment: a type of stimulus-response compatibility task in which the color of a graspable object is used as relevant attribute in a Stroop-matching task. This is important, because not all studies using graspable objects in Simon-like tasks have revealed significant correspondence (or compatibility) effects, and the conditions necessary to generate a significant facilitation have been debated (Tucker & Ellis, 1998; Symes et al., 2005; Tipper et al., 2006, Cho & Proctor, 2010, 2011, 2013; Makris et al., 2011; McNair et al., 2017). Thus, a main effect for the factor hand-handle correspondence and a positive correspondence effect in Experiment 1 would confirm the existence of a correspondence effect under the conditions adopted. Furthermore, since both the correspondence effect (if found) and the SMRC presumably occur at response level, an interaction between them is feasible. However, although the SMRC occurs due to an erroneous response code generation at response stage, it starts from an unnecessary match, in which the irrelevant Stroop attribute (the color) could not be ignored, generating an improper semantic-perceptual processing at pre-response stage. Alternatively, absence of interaction is also possible, denoting that the irrelevant spatial cue (the handle) does not affect the processing of the irrelevant Stroop attribute and the generation of the erroneous response code. Some papers have already searched for these possible interactions using flanker (Fan et al., 2002, 2005; Chajut et al., 2009) and color-word Stroop tasks (Vivas & Fuentes, 2001; Chen, 2003; Chajut et al., 2009; Choi et al., 2009), but the results are still controversial. However, as far as we know, our study is the first to search for those interactions using graspable objects instead of explicit lateralized stimuli as spatial cues.

In the second experiment, graspable objects were replaced by lateralized or centered colored bars. It allowed a direct investigation of the two competing hypotheses to explain the correspondence effect in Experiment 1. The lateralized colored bars

should automatically orient spatial attention, and because no graspable part is present in those images, no “affordance effect” is expected. Thus, similar patterns of results in both experiments would favor a common mechanism for the correspondence effect, that is, the spatial coding hypothesis. Instead, different results between experiments would indicate distinct processes mediating the correspondence effect in Experiments 1 and 2.

Therefore, in both experiments, the Stroop stimulus must be compared with a stimulus that cannot be considered spatially neutral, due to the intrinsic spatial characteristics of the stimulus itself (Experiment 1) or because of its presentation position (Experiment 2). It represents an important and innovative aspect of the present study, since it permits: (1) to explore the presence of motor laterality effects related to the spatial characteristics of the stimuli in a Stroop-matching task context; (2) to test possible interactions between the laterality effects and the SMRC, supporting or not the presence of similar mechanisms at the basis of both phenomena; (3) to compare stimuli that have a motor significance (graspable objects) with stimuli that do not have such an impact on the motor system, to clarify the nature of the laterality effects when graspable objects are used.

Other relevant aspects of our study are the use of intact and broken handles in the first experiment. This also allows assessing, indirectly, the attentional shift/spatial-coding and the grasping affordance views. The attentional view predicts that intact and broken handle conditions should not differ in their capacity to facilitate ipsilateral responses, since both have the salient part of the object laterally oriented. However, according to the grasping affordance account, only in the intact handle condition, the motor programs necessary to reach and grasp the cup should be activated, given that when the handle is violated (the broken condition), the motor programs related to object manipulation are inhibited or not activated at all (Buccino et al., 2009). This premise will be tested by searching for an interaction between the factors handle and hand-handle correspondence.

Furthermore, we also extended our protocol into another important aspect: we manipulated the interval between stimuli presentation to assess possible time-related modulations in the correspondence effect for both intact and broken handles in Experiment 1, and for colored bars in Experiment 2. Our study is also the first to include two time intervals (100 and 800 ms) and intact vs. broken handles in the same protocol. Potentially, this allows investigating the time dynamics of facilitatory and/or

inhibitory mechanisms generated by intact/broken handles and colored bars in the context of a new stimulus-response compatibility task. If modulation in performance arises from automatic mechanisms, it should occur at short intervals, while controlled processes should emerge at 800 ms. Putative time modulation on the conflicts mentioned will be tested by searching for interactions between the factor interval and other critical factors.

Summarizing, by means of two experiments, we tested in a Stroop-matching task context the presence of the correspondence effect for lateralized handles and bars, and its possible influence on SMRC. Moreover, we hope to clarify the contribution of attentional shift/spatial coding and grasping affordance in the correspondence effect and the time dynamics of facilitation/inhibition generated by graspable objects and lateralized colored bars.

## **Experiment 1**

### **Methods**

#### **Participants**

Twenty-five undergraduate and graduate students (16 females; mean age = 25.7  $\pm$  6.9) from the University of Parma volunteered to take part in the experiment. The sample size was based on our prior experiments with Stroop-matching tasks already published (e.g., Caldas et al., 2012, 2014). Furthermore, the G\*Power 3.1.9.2 software confirmed that we needed at least 23 participants to detect a medium effect size ( $f=0.25$ ) with a 5% probability for committing a type I error ( $\alpha=0.05$ ) and a 5% probability for a type II error ( $1-\beta=0.95$ ) (Faul et al., 2007). All participants were right-handed or two-handed as assessed by the Edinburg handedness inventory (Oldfield, 1971), had normal or corrected-to-normal visual acuity and normal color vision (Ishihara, 1972), and were unaware about the purposes of the experiment. All the experimental procedures were in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and with the requirements of the Ethics Committee of the University of Parma. Participants gave written informed consent before the study.

#### **Apparatus**

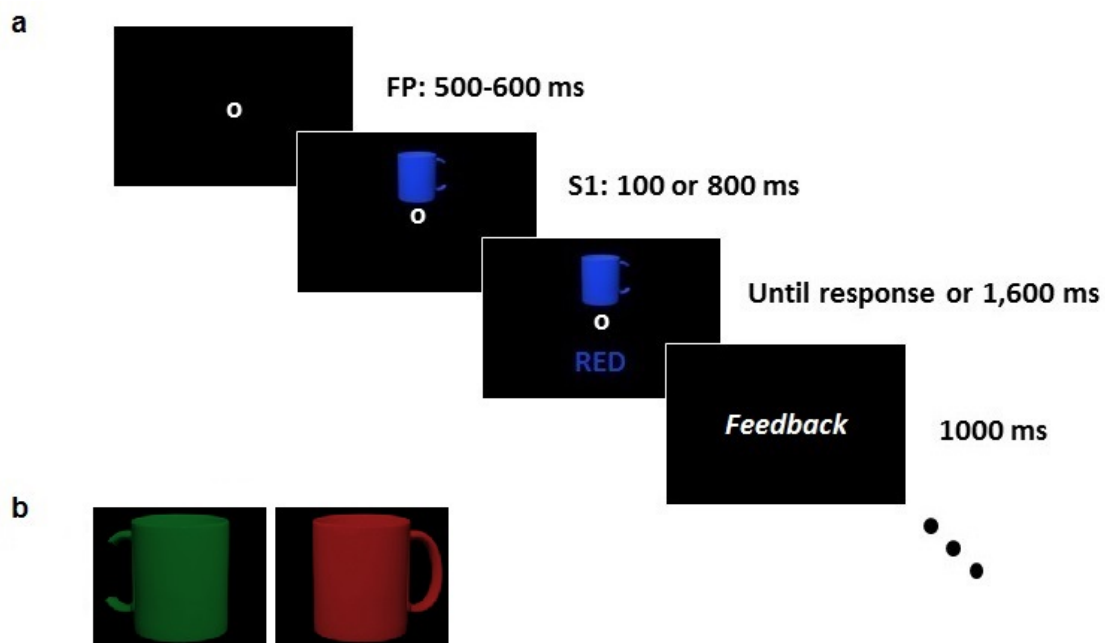


The experiment was conducted in a sound-attenuated room, dimly illuminated by an LED lamp directed toward the ceiling. The participants sat comfortably in front of a LCD monitor (Elo Tyco Electronics with a resolution of 1920 x 1080 pixels) with their head resting in a support to maintain the head position stable and keep their eyes at a constant distance (approximately 50 cm) from the screen. Eye height was adjusted to the level of fixation point. A microcomputer running E-Prime v2.0 software (Psychological Software Tools Inc.) timed the presentation of the stimuli and recorded the manual responses. A keyboard was placed on a table between the participant and the monitor, and responses were executed by pressing the “1” (on the numeric pad) and the “Z” keys with the right and the left index fingers, respectively. Response keys were in symmetrical positions with respect to the body midline. Participants were required to keep their index fingers on these keys during the experimental session.

### **Stimuli and procedure**

Two types of stimuli were presented to participants: the photograph of a cup (11.5 x 11.5 cm) combined with a color-word (2.5 x 2.5 cm for each letter) in a congruent or incongruent color (Stroop stimulus), as can be seen in Fig 1. The color-words (RED, GREEN, or BLUE) and the cups were colored in red, green or blue ink. Each trial started with a fixation point (FP) that was presented for 500-600 ms. Then, the first stimulus (S1) was presented and after 100 or 800 ms the second stimulus (S2) appeared. S1 consisted of photographs of real cups digitally colored with their bodies (8.5 cm/width x 11.5 cm/height) displayed in the center of the screen, having an intact or a broken handle (3.0 cm) oriented to the right or to the left (suitable for a right-hand or a left-hand grasp). S2 consisted of a congruent (e.g., RED in red) or incongruent (e.g., RED in blue) Stroop stimulus. Participants were instructed to match the color of S1 to the meaning (word) of S2 as quickly as possible – reaction time (RT). Half of the participants should press the “1” key with the right index finger if they were “same” and the “Z” key with the left index finger if they were “different”. The remaining participants experienced the reverse response mapping, i.e., press “Z” if the color of the cup and the word of S2 were “same” and “1” if they were “different”. Both stimuli remained on the screen until the emission of the manual response (or until 1600 ms elapsed), and a new trial began after the feedback of response accuracy, which remained on the screen for 1000 ms. Response accuracy was delivered by means of the messages

“anticipation” (when RTs were shorter than 150 ms), “slow responses” (RTs longer than 1600 ms), “correct” (RTs were between 150 and 1600 ms and the correct key was pressed), or “incorrect key-press” (RTs were between 150 and 1600 ms and the incorrect key was pressed). There was only one experimental session composed of 384 trials (192 for “same” and 192 for “different” responses) divided into 4 blocks of 96 trials with a few minutes of rest between the blocks. Each block lasted for about 5 min and the full duration of the experiment was about 30 min. Before the experimental session, participants executed a shorter block of familiarization trials (thirty trials) in which the same stimuli of the experimental trials were used.



**Fig 1. a) Experimental paradigm: sequence of events and duration of stimuli in Experiment 1. S1 was a colored cup with an intact or a broken handle oriented to the right or to the left and S2 was a congruent or an incongruent Stroop stimulus. b) Examples of green and red cups presented with broken and intact handles.**

### Data analysis

Incorrect key presses rates and correct reaction times (RTs) were entered into two separate repeated-measures analyses of variance (ANOVAs) with handle (intact and broken), handle-hand correspondence (corresponding and non-corresponding), Stroop-matching response conflict (with and without) and interval (100 ms and 800 ms) as within-subject factors. These overall ANOVAs allowed testing the main effects and possible interactions among all factors manipulated in the experiment, having accuracy

and mean RT as dependent measures. For all ANOVAs, partial eta-squared ( $\eta_p^2$ ) was calculated as an estimate of effect size, and when appropriate, the Newman-Keuls *post-hoc* test was performed. The  $\alpha$ -level adopted for statistical significance was 0.05.

## Results

### Response conflict analysis

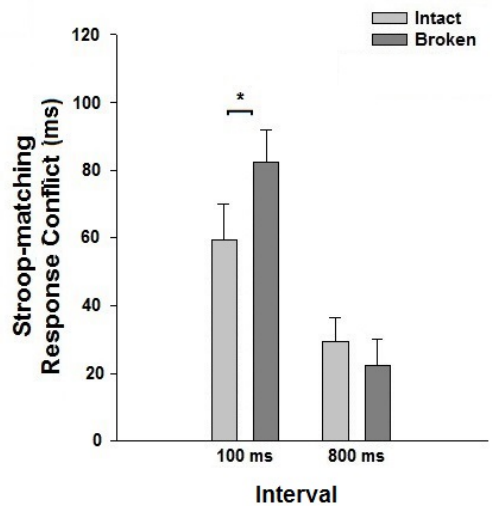
#### *Incorrect key presses analysis*

The overall mean percentage of errors among all participants was 4.3% (415 errors in 9600 trials). The ANOVA showed significant main effects for correspondence [ $F(1,24)= 11.50, p= 0.002, \eta_p^2= 0.324$ ], Stroop-matching response conflict [ $F(1,24)= 19.90, p< 0.001, \eta_p^2= 0.453$ ] and interval [ $F(1,24)= 26.53, p< 0.001, \eta_p^2= 0.525$ ]. Incorrect key-presses were more frequent for non-corresponding trials (5.2%) than for corresponding ones (3.8%), for trials with Stroop-matching response conflict (5.6%) than for trials without Stroop-matching response conflict (3.4%) and at 100 ms interval (6.2%) compared to 800 ms interval (2.8%). The interactions between correspondence and interval [ $F(1,24)= 14.20, p< 0.001, \eta_p^2= 0.372$ ] and between Stroop-matching response conflict and interval [ $F(1,24)= 11.62, p= 0.002, \eta_p^2= 0.326$ ] were also significant, indicating that the two response conflicts were affected by the interval. The *post-hoc* analysis revealed that the differences between non-corresponding and corresponding trials and between trials with and without Stroop-matching response conflict were only significant at 100 ms intervals (7.9% vs. 4.5%, and 8.1% vs. 4.3%, respectively,  $p< 0.001$  for both comparisons). At 800 ms these same differences did not reach significance (2.5% vs. 3.1%, and 3.1% vs. 2.5%, respectively,  $p> 0.05$  for both comparisons).

#### *Reaction time analysis*

The ANOVA showed significant main effects for all factors: handle [ $F(1,24)= 8.92, p= 0.006, \eta_p^2= 0.271$ ], correspondence [ $F(1,24)= 4.90, p= 0.037, \eta_p^2= 0.169$ ], Stroop-matching response conflict [ $F(1,24)= 64.74, p< 0.001, \eta_p^2= 0.730$ ] and interval [ $F(1,24)= 302.89, p< 0.001, \eta_p^2= 0.927$ ]. Longer RTs were observed for broken handles (630 ms) in relation to intact handles (616 ms); for non-corresponding in relation to corresponding trials (626 and 620 ms); for trials with Stroop response conflict compared to trials without Stroop response conflict (647 and 599 ms) and at 100 ms in relation to

800 ms interval (710 and 537 ms). Again, as observed for the incorrect responses, the interactions between Correspondence and Interval [ $F(1,24)= 5.96, p= 0.022, \eta_p^2= 0.199$ ] and between Stroop-matching response conflict and Interval [ $F(1,24)= 20.39, p< 0.001, \eta_p^2= 0.459$ ] were also significant. The *post-hoc* analysis revealed that the difference between non-corresponding and corresponding trials was only significant at 100 ms interval (718 and 702 ms,  $p= 0.007$ ). At 800 ms the difference did not reach significance (535 and 538 ms,  $p= 0.639$ ). Instead, the differences between trials with and without Stroop-matching response conflict reached significance at both intervals, being higher in the short one [745 and 674 ms (diff = 71 ms) at 100 ms,  $p< 0.001$ ; and 550 and 524 ms (diff = 26 ms) at 800 ms,  $p= 0.001$ ]. Critically, no interaction was obtained between handle-hand correspondence and Stroop-matching response conflict ( $p= 0.269$ ): irrespective of whether the correct response was ipsilateral or contralateral to the handle, the magnitude of the Stroop-matching response conflict did not vary significantly (46 and 51 ms, respectively). The three-way interaction among handle, Stroop-matching response conflict and interval was also significant [ $F(1,24)= 11.85, p= 0.002, \eta_p^2= 0.331$ ], which indicates that interval affected the way the handle and Stroop-matching response conflict interacted. The *post-hoc* analysis showed that, at both intervals, trials with Stroop-matching response conflict were longer than trials without Stroop-matching response conflict for broken (respectively, 758 and 676 ms at 100 ms; 554 and 532 ms at 800 ms) and for intact handles (732 and 673 ms at 100 ms; 545 and 515 ms at 800 ms);  $p< 0.001$  for all comparisons. Moreover, Student's *t* tests complemented these findings by showing that the SMRC magnitude (the RT difference between trials with and without Stroop-matching response conflict) was significantly higher for broken than for intact handles at 100 ms (82 ms and 59 ms, respectively;  $t(24)= 2.50, p= 0.020$ ), but not at 800 ms (22 ms and 30 ms, respectively;  $p= 0.335$ ) – Fig 2. In short, the SMRC magnitude was greater for broken than intact handles, but only at 100 ms.



**Fig. 2. Stroop-matching response conflict magnitude (difference between trials with and without Stroop-matching response conflict) for broken and intact handles at 100 and 800 ms intervals. The bars depict standard errors of the means; \* $p < 0.05$ .**

## Experiment 2

### Methods

#### Participants

Thirty undergraduate and graduate students (16 females; mean age =  $23.5 \pm 5.8$ ) from the Fluminense Federal University (Brazil) volunteered to take part in the experiment. Twenty-three participants were right-handed, five were two-handed and two were left-handed as assessed by the Edinburgh handedness inventory (Oldfield, 1971). All had normal or corrected-to-normal visual acuity, normal color vision (Ishihara, 1972) and were unaware about the purposes of the experiment. Again, the experimental procedures were in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and were approved by of the Ethics Committee of the University. Participants gave written informed consent before the study.

#### Apparatus

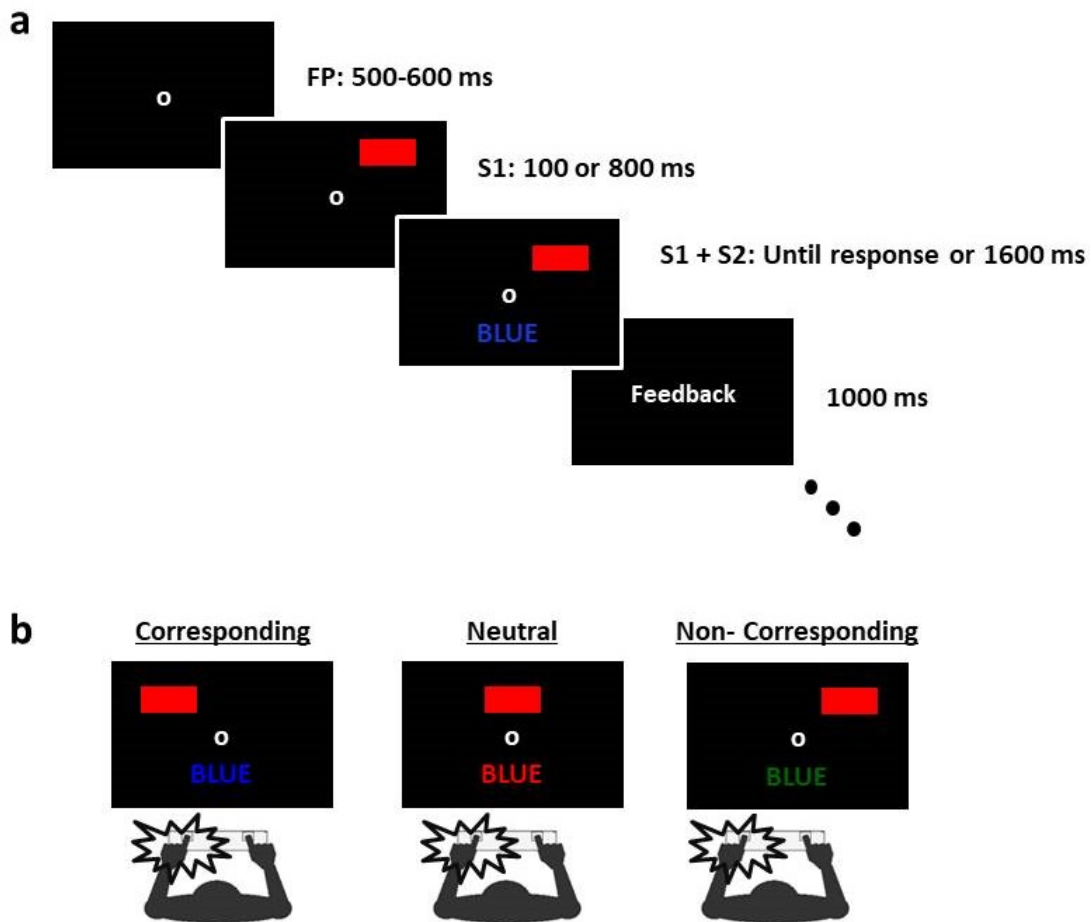
The same apparatus of Experiment 1 was adopted, except that the resolution of the LCD monitor was 1280 x 768 pixels and participants' heads were positioned to keep their eyes at approximately 57 cm from the screen. Again, E-Prime v2.0 software (Psychological Software Tools Inc.) timed the presentation of the stimuli and recorded

the manual responses obtained by means of a keyboard placed on a table between the participant and the monitor.

### **Stimuli and procedure**

Two visual stimuli were used: a colored bar (3.5 cm/width x 0.9 cm/height) and a congruent or incongruent Stroop stimulus (0.9 x 0.9 cm for each letter). The Stroop stimuli (the words RED, GREEN or BLUE) and the bars were colored in red, green or blue ink. Each trial started with a FP presented for 500-600 ms followed by a colored bar (S1) presented 1.5° above the FP on three possible positions: exactly above the FP (centrally), 7.5° on the left or 7.5° on the right – see Fig. 3. Then, after 100 or 800 ms the Stroop stimulus (S2) appeared 1.5° below the FP, always centrally. As in Experiment 1, participants were instructed to match the color of the bar to the meaning (word) of S2 as soon as possible (RT). Half of the participants should press the “1” key with the right index finger if they were “same” and the “Z” key with the left index finger if they were “different”. The remaining participants experienced the reverse response mapping. Both stimuli remained on the screen until the emission of the manual response (or until 1600 ms elapsed), and a new trial began after the feedback of response accuracy, which remained on screen for 1000 ms. Feedbacks of response accuracy were identical to Experiment 1.

There was only one experimental session composed of 432 trials (216 for “same” and 216 for “different” responses) divided into 4 blocks of 108 trials with a few minutes of rest between blocks. The full duration of the experiment was about 30 min. Before the experimental session, participants executed a shorter block of familiarization trials (thirty trials) in which the same stimuli were used.



**Fig. 3. a) Experimental paradigm: sequence of events and duration of stimuli in Experiment 2. S1 was a lateralized or centered colored bar and S2 was a congruent or an incongruent Stroop stimulus centrally presented. b) Examples of corresponding, neutral and non-corresponding trials.**

### Data analysis

Following the same procedure adopted in Experiment 1, incorrect key presses rates and correct reaction times (RTs) were entered into two separate repeated-measures ANOVAs with bar-hand correspondence (corresponding, neutral, and non-corresponding), Stroop-matching response conflict (with and without) and interval (100 ms and 800 ms) as within-subject factors. Finally, an overall ANOVA was conducted to compare RTs obtained in Experiments 1 and 2, considering only the factors that were common to both experiments. Thus, handle (intact and broken – Experiment 1) and the condition neutral (Experiment 2) were not included. In this overall ANOVA, Experiments (1 and 2) were used as between-factor, and correspondence (corresponding

and non-corresponding), Stroop-matching response conflict (with and without) and interval (100 ms and 800 ms) as within-subject factors. For all ANOVAs, partial eta-squared ( $\eta_p^2$ ) was calculated as an estimate of effect size, and when appropriate, the Newman-Keuls *post-hoc* test was performed. The  $\alpha$ -level adopted for statistical significance was 0.05.

## Results

### *Incorrect key presses analysis*

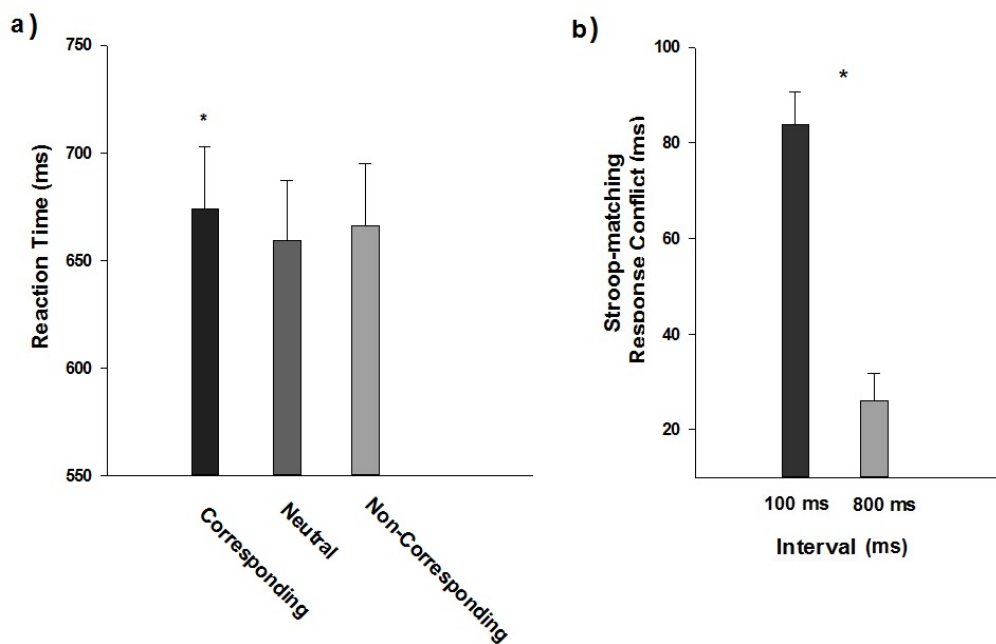
The mean percentage of errors among all participants was 5.1% (666 errors in 12960 trials). The ANOVA showed a significant main effect for interval [ $F(1,29)=45.42, p<0.001, \eta_p^2=0.610$ ], in which incorrect key-presses were more frequent at 100 ms than at 800 ms interval (7.1% vs. 3.1%). The interaction between Stroop-matching response conflict and interval was almost significant [ $F(1,29)=3.88, p=0.058, \eta_p^2=0.118$ ], and the *post-hoc* analysis indicated that differences between trials with and without Stroop-matching response conflict occurred at 100 ms intervals (8.0% vs. 6.3%,  $p=0.013$ ), but not at 800 ms (3.1% vs. 3.2%,  $p=0.882$ ).

### *Reaction Time analysis*

RT ANOVA showed significant main effects for all factors: correspondence [ $F(2,58)=7.87, p<0.001, \eta_p^2=0.213$ ], Stroop-matching response conflict [ $F(1,29)=102.22, p<0.001, \eta_p^2=0.779$ ] and interval [ $F(1,29)=331.26, p<0.001, \eta_p^2=0.919$ ]. The interaction between Stroop-matching response conflict and interval was also significant [ $F(1,24)=70.76, p<0.001, \eta_p^2=0.459$ ]. Longer RTs were observed at 100 ms in relation to 800 ms interval (751 and 580 ms), and for trials with Stroop response conflict compared to trials without Stroop response conflict (694 and 639 ms). The *post-hoc* analysis for the factor correspondence revealed that RTs for corresponding trials were longer (674 ms) than those obtained for neutral (659 ms;  $p<0.001$ ) and non-corresponding ones (666 ms;  $p=0.036$ ), which did not differ. Despite not being significant ( $p=0.559$ ), we will mention the MRTs obtained for each condition in both intervals to allow a comparison with Experiment 1. At 100 ms MRTs were 767, 748 and 761 ms; at 800 ms MRTs were 598, 584 and 587 ms, respectively for corresponding, neutral and non-corresponding trials. Importantly, as in the Experiment 1, the absence of a significant interaction between correspondence and Stroop-matching response



conflict ( $p= 0.402$ ) revealed that the magnitude of the Stroop-matching response conflict did not vary significantly among corresponding (60 ms), neutral (55 ms) and non-corresponding trials (50 ms). The *post-hoc* analysis of the interaction between Stroop-matching response conflict and Interval revealed that the difference between trials with and without Stroop-matching response conflict reached significance at both intervals, being higher in the short one [794 and 710 ms (diff = 84 ms) at 100 ms; and 594 and 568 ms (diff = 26 ms) at 800 ms,  $p < 0.001$  for all comparisons]. In short and critically to our aims, no facilitatory effect was found for corresponding trials – see Fig. 4.



**Fig. 4. Main results of Experiment 2. a) Reaction times obtained for corresponding, neutral and non-corresponding trials. b) Stroop-matching response conflict magnitude (difference between trials with and without Stroop-matching response conflict) obtained for the intervals of 100 ms and 800 ms. The bars depict standard errors of the means; \* $p < 0.05$ .**

The overall ANOVA revealed main effects for Stroop-matching response conflict [ $F(1,53)= 146.54$ ,  $p < 0.001$ ,  $\eta_p^2= 0.734$ ] and interval [ $F(1,53)= 527.40$ ,  $p < 0.001$ ,  $\eta_p^2= 0.908$ ]. Significant interactions occurred between Stroop-matching response conflict and interval [ $F(1,53)= 68.67$ ,  $p < 0.001$ ,  $\eta_p^2= 0.564$ ], correspondence and interval [ $F(1,53)= 4.59$ ,  $p= 0.036$ ,  $\eta_p^2= 0.079$ ], and correspondence and experiment [ $F(1,53)= 8.81$ ,  $p= 0.004$ ,  $\eta_p^2= 0.142$ ]. Most of these data only replicate the results already described in both experiments, and so they will not be detailed again. The critical point of this overall ANOVA is the absence of a main effect for Correspondence

and the significant interaction between experiment and correspondence, which confirm that the pattern obtained for the correspondence effect differed between experiments. The *post-hoc* analysis revealed that while in Experiment 2 corresponding and non-corresponding trials differed significantly (666 and 674 ms, respectively, a negative correspondence effect;  $p= 0.024$ ), in Experiment 1, this difference did not reach significance (626 and 620 ms, respectively, an almost significant positive correspondence effect,  $p= 0.064$ ). Moreover, t-tests comparing the magnitude of the correspondence effect between experiments revealed that significant differences occurred in the overall correspondence effect (6 ms and -8 ms, respectively for Experiment 1 and 2;  $p= 0.002$ ) and also at 100 ms (16 ms and -6 ms, respectively;  $p= 0.006$ ), but not at 800 ms (-3 ms and -9 ms, respectively;  $p= 0.101$ ).

## **Discussion**

In the first experiment, we developed a variation of the Stroop-matching task in which subjects matched a Stroop stimulus to a central colored cup with its handle laterally oriented. This protocol was used to verify if the SMRC might be influenced by the correspondence effect generated by the lateral handle. In other words: can an irrelevant spatial cue (the handle) interfere with the processing of the two Stroop attributes and so affect the magnitude of the SMRC for corresponding and non-corresponding trials? Furthermore and importantly, we presented the colored cup with intact or broken handles to understand the mechanisms underlying the handle-hand correspondence effect. In the second experiment, the colored cup was replaced by a lateralized (or centered) bar to investigate directly whether the pattern of results obtained in Experiment 1 was better explained by the attentional shift or the grasping affordance hypothesis. Finally, the insertion of two different intervals between stimuli allowed investigating time-modulations in behavioral performance in both experiments.

A significant correspondence effect was obtained in the first experiment, which agrees with the stimulus-response compatibility literature, since we observed longer RTs and higher error rates in non-corresponding than corresponding trials. As previously described, this pattern of results could be explained in terms of two different accounts: the grasping affordance or the attentional shift/spatial coding accounts. The fact that a significant correspondence effect was found in the first experiment means

that the handle was able to generate activation for ipsilateral manual responses; therefore, the protocol used in the first experiment can also be considered a type of stimulus-response compatibility task. However, when the cup was replaced by lateralized bars (Experiment 2) facilitation was not found for corresponding trials; actually RTs were significantly slower for ipsilateral responses. This issue will be discussed in a specific topic ahead. In the following paragraphs we extensively discuss our results according to three main issues: (1) the Stroop-matching response conflict for graspable and non graspable objects; (2) the Stroop-matching response and the correspondence conflicts; (3) the correspondence effect for graspable and non-graspable objects: grasping affordance versus attentional/spatial coding accounts.

### **The Stroop-matching response conflict for graspable and non graspable objects**

The pattern of data obtained for graspable and non-graspable objects agreed with the SMRC literature (e.g., Goldfarb & Henik, 2006): trials with SMRC presented slower responses and higher error rates. In other words, congruent trials presented faster RTs for the “same” responses and slower RTs when the correct response was “different”, while incongruent trials presented faster RTs for “different” responses and slower RTs when the correct response was “same”. These results also confirm previous studies of our group in which a centrally presented bar was used as S1 (Caldas et al., 2012, 2014) and reveal that the use of spatially oriented stimuli, cups with intact or broken handles and lateralized bars, did not change the pattern usually observed in a Stroop-matching task. Importantly, the magnitude of the SMRC was modulated by the interval: SMRC was significantly greater at 100 ms than at 800 ms. This time modulation indicates that the unnecessary and erroneous match between both relevant and irrelevant Stroop attributes, which ultimately generates the SMRC, has its origin in a fast and automatic mechanism that gradually decreases. Moreover, Experiment 1 also revealed that the SMRC magnitude was significantly higher for broken than for intact handles, but only at 100 ms. A possible explanation for this finding is related to the perceptual conflict hypothesis. This assumes that a participant is unable to completely restrict his/her attention to the relevant aspects of a task, and therefore, the processing of irrelevant stimuli can disrupt or delay the processing of relevant ones when the perceptual demand is enhanced due to the division of limited processing capacity (Hock & Egeth, 1970). Other studies have already confirmed that the perceptual demand really affects the way

relevant and irrelevant stimuli are processed, in both Stroop (Williams, 1977; Chen, 2003) and affordance (Murphy et al., 2012) protocols. In the context of our task, we assume that a cup with a broken handle is perceptually more demanding than an intact one, probably because the image of a broken handle disrupts the visual representation expected for a cup. In support of this idea is the main effect of handle (see reaction time analysis), showing that participants are slower to respond to a cup with the broken than with the intact handle. This explanation has similarities with the perceptual load hypothesis proposed by Lavie and co-workers, which states that the amount of stimuli processing is a function of the attentional demand of the whole task (Lavie & Tsai, 1994; Lavie et al., 2004). In a more recent view, Lavie et al. (2004) proposed that active attentional mechanisms modulate distractor interference. These mechanisms reduce interference from perceived distractors as long as cognitive control functions are available to maintain current priorities, which occurs under low cognitive load. Higher demanding tasks would drain the capacity available to apply inhibitory active control, increasing the processing of irrelevant information. Thus, tasks with higher perceptual demands (the broken condition) would overload cognitive control mechanisms and impair the allocation of active resources necessary to reduce the interference observed in the Stroop-matching conflict, increasing its magnitude. It explains the increased SMRC magnitude at short-time interval for broken handles in comparison with the intact cup condition. Moreover, the fact that this interference was only observed at 100 ms indicates that it was due to short-lived automatic mechanisms, which were possibly overcome by controlled processes in the long interval.

### **The Stroop-matching response and the correspondence conflicts**

One important aim of the present study was to test the possible interference between the SMRC and the correspondence effect. Since both the correspondence effect and the SMRC are supposed to occur at response level (e.g., Alluisi & Warm, 1990; Proctor & Vu, 2006 – for the correspondence effect; and Goldfarb & Henik, 2006; Caldas et al., 2012 – for the SMRC), an interaction between them should be expected. However, this was not confirmed and the interaction was not found in both experiments. Two possible explanations emerge. The first is that although both conflicts occur at response level, each one involves different and relatively independent response-related mechanisms. The second possibility is that the conflicts occur at different levels of

processing. While the correspondence conflict occurs unequivocally at response selection/execution stages, the basis of the SMRC, instead, could be in another level of processing. According to this hypothesis, the SMRC though generating an erroneous response code would be primarily originated in inhibitory functions of the executive system, the so-called control of stimulus interference (Stahl et al., 2014) or distracter interference (Friedman & Miyake, 2017), i.e., the incapacity to inhibit the irrelevant Stroop attribute (at pre-response level) and avoid the improper match that lastly generated the erroneous response code. Our protocol does not permit to be conclusive in relation with these two possibilities, but our data clearly indicate that the mechanisms underlying the correspondence effect and the Stroop-matching response conflicts do not interact, at least under the specific conditions adopted here. The absence of interaction is supported by the previous studies. For example, Chajut et al. (2009) found that the congruency effect was not affected by the spatial cue when a classical color-word Stroop task was used to access the executive system (their Experiment 3): congruency effects did not differ for valid and invalid trials. However, when spatial demands were necessary to perform the executive task, the spatial orientation did interfere in the performance. Thus, interference was observed in a global vs. local spatial Stroop task (Experiment 1), in a spatial flanker task (Experiment 2) and when a color-word Stroop task was used (Experiment 4), but the two dimensions of the Stroop stimulus (color and word) were spatially segregated. In short, this pattern of results indicates that interference in inhibitory functions of executive control by spatial cues occurs only when spatial demands are shared between both systems. A similar conclusion was achieved by Fan et al. (2002, 2005) using the flanker task. However, other studies using color-word Stroop tasks with inhibition of return (Vivas & Fuentes, 2001; Choi et al., 2009) or with spatially predictive cues (Chen, 2003) showed that spatial orienting of attention affected the executive task performance even when no spatial demand occurred. Thus, controversial results have been obtained, and therefore, there is no consensus regarding the conditions necessary to generate those interactions. In any case, our data support the hypothesis of different and relatively independent psychological mechanisms at the basis of the two effects, but other investigations are probably needed to clarify this issue.

## **The correspondence effect for graspable and non-graspable objects: grasping affordance versus attentional/spatial coding accounts**

The results obtained in Experiments 1 and 2 regarding the correspondence effect were clearly discrepant. Graspable objects generated an overall positive correspondence effect that significantly differed from that obtained for lateralized bars. This general pattern was replicated at 100 ms, but at 800 ms the correspondence effect did not differ between both experiments. Actually, data from Experiment 1 revealed a clear modulation of the correspondence effect by the interval; RTs were longer and error rates were higher for non-corresponding trials only at 100 ms. The absence of significant differences between corresponding and non-corresponding trials at 800 ms indicates that the activation of the ipsilateral hand is a transient phenomenon that fades over time, not affecting performance at long intervals. The time course of facilitation/inhibition induced by graspable objects has already been studied. Makris et al. (2011), using objects associated to power or precision grip, showed that RTs and motor evoked potentials were facilitated after the visualization of graspable objects only at the shortest intervals they used: 400 ms for RTs and 300 ms for motor evoked potentials. For longer intervals, facilitation disappeared, leading to the conclusion that facilitation is rapid and relatively short-lived. Goslin et al. (2012) obtained similar results by showing that event-related activity associated with motor preparation occurred shortly after the visualization of graspable objects in corresponding hands, and then disappeared. Curiously, Lien et al. (2013) did not replicate Goslin et al.'s results, despite using the same procedures. In a recent study, McNair et al. (2017) also found that facilitation on motor evoked potential was consistently obtained only at the shortest interval they used (167 ms), even when the behavioral performance indicated that objects did not reach full conscious identification (attentional blink protocol). They also concluded that the motor system is automatically activated during the visual processing of objects that afford actions, such as our results indicate.

The absence of a significant positive correspondence effect in the second experiment, when lateralized bars were introduced, represents an important finding of this study. First, it allowed accessing directly the two hypotheses to explain the facilitation of ipsilateral motor responses observed in Experiment 1. According to the grasping affordance account, when the handle was ipsilateral to the hand involved in the manual response, automatic hand activation would occur (ipsilateral facilitation),

leading to fast manual responses. Otherwise, non-corresponding trials imply that the motor program automatically recruited by the handle must be cancelled and another motor program should be generated to produce the required motor response involving the opposite (correct) hand, causing longer manual reaction times. On the other hand, the attentional shift/spatial-coding view postulates that the ipsilateral facilitation occurs, because the handle renders the cup asymmetrical; hence, this salient part should capture attention to its location, which primes (and facilitates) ipsilateral responses. Thus, any object (or condition) that attracts attention laterally should be able to generate the correspondence effect. Clearly, this did not occur in our Experiment 2, since no facilitation was observed for ipsilateral responses; instead, inhibition for ipsilateral responses was obtained. Based on this critical finding, we conclude that the correspondence effect obtained in the first experiment is better explained by the grasping affordance hypothesis; the cup's handle automatically generates a motor program to reach and grasp it, and therefore, ipsilateral motor responses are facilitated.

At first glance, the negative correspondence effect obtained in the second experiment should sound very intriguing, since many classical studies have already detected facilitation for ipsilateral motor responses at short intervals (100 ms) when lateralized stimuli are presented – the attentional capture (e.g., Posner & Cohen, 1984; Fukuda & Vogel, 2011; for a review, see Chica et al., 2013). Moreover, those spatial orienting studies have also revealed that after 200/300 ms the processing of ipsilateral targets is delayed, a mechanism referred to as inhibition of return - IOR (Klein, 2000; Riggio et al., 2006). The canonical explanation of this inhibitory aftereffect is that it represents a bias against returning the attention to other ipsilateral events, and has been consistently demonstrated in different contexts (e.g., Berlucchi, 2006; Lupiañez et al., 2006). It is very important to notice that in those studies, both the cue (S1) and the target (S2) were laterally presented. However, we emphasize that in this study, S2 was not laterally presented: Stroop stimulus was always central, neither ipsi nor contralateral to S1. Thus, any putative facilitatory effect could not be attributed to facilitation detecting an ipsilateral S2. Another important aspect is that our experiments cannot be considered a typical orienting or detection task. More than simply detecting S2 and pressing the spatially correspondent key, participants should retain the color of S1 (cup or bar) and match it to the word-attribute of the Stroop stimulus before pressing the correct key. Therefore, a direct comparison between our results and those obtained in

typical spatial orienting protocols is not simple, since the cognitive requirements are clearly different. Yet, the bias against returning attention to manage other ipsilateral events could be an explanation for the ipsilateral inhibition obtained in Experiment 2, an IOR-like mechanism. However, since the target was not laterally presented, this putative IOR-like mechanism that delayed ipsilateral responses would not be influencing S2 detection. Instead, this mechanism would inhibit the activation of the ipsilateral hand; again, not a canonical explanation for the IOR. Further studies using protocols more similar to ours are necessary to confirm this finding and to test the viability of this hypothesis.

Interestingly, in the first experiment, a positive correspondence effect was also found for broken handle objects at 100 ms. By definition, a broken handle is not graspable, and therefore, facilitation should not be expected. The alternative explanation for this facilitation, based on the attentional shift view, appears not justified according to the results of Experiment 2. Anyway, the finding of facilitation for broken handles at 100 ms indicates that motor programs were also automatically activated for broken handles at 100 ms. A possible explanation for this facilitation at the short interval is based on the time dynamics of the effect. Because this activation is fast and automatic, it would occur even before the perceptual processing is completed, and therefore, according to this view, at 100 ms both types of handles could favor ipsilateral responses. Since our study is the first to adopt broken vs. intact handle with different time intervals, we believe that more studies could help to better understand the time dynamics of facilitation/inhibition observed for graspable objects with intact and broken handles.

Finally, time dynamics obtained in our study revealed some important findings regarding the possible ways that graspable objects (with intact or broken handles) are processed. Actually, the mechanisms underlying the correspondence effect for graspable objects remain as a source of debate. In an impressive series of experiments, Cho and Proctor (2010, 2011, 2013) provided evidence that the correspondence effect observed for graspable objects was due to hand facilitation caused by the relative location of the object's handle, favoring the spatial coding view. It challenged our interpretation that favors the grasping affordance view. However, it is worth mentioning that they used silhouette-like objects instead of photographs of real objects. Some authors (Symes et al., 2007; Pappas, 2014) have already proposed that the lack of some object's internal



details (such as depth information, shading, and contour lines) hampers the activation of appropriate motor programs afforded by the handles. Thus, the use of silhouette-like objects by Cho and Proctor, instead of more realistic objects, would hamper affordance-related activations weakening the affordance interpretation. In a more recent study, Proctor et al. (2017) investigated the role of different aspects on object-based correspondence effects: silhouette vs. photograph images of objects; near vs. far response keys; and within- vs. between-hand responses. Despite concluding that the correspondence effect is primarily driven by spatial coding, they also found a contribution of an effector-specific correspondence component when photographs of graspable objects are used. In the present study, we used photographs of real cups and not silhouettes. Moreover, objects were presented in real size according to the distance between the observer and the computer screen. All of these features favor the activation of appropriate motor programs. Consequently, the reasons pointed out by some authors to discredit the grasping affordance hypothesis cannot be considered here, which remains as the most plausible explanation to our data, mainly because of the results obtained in Experiment 2.

## **Conclusions**

We developed a new protocol in which Stroop stimuli were matched to graspable objects with intact or broken handles laterally oriented (Experiment 1) or to colored bars laterally presented (Experiment 2). In both experiments, significant SMRC was found (being greater at 100 ms in relation to 800 ms) but no interaction occurred between the SMRC and the correspondence effect, supporting the hypothesis of different and relatively independent psychological mechanisms that are at the basis of the two effects. Facilitation for ipsilateral motor responses (correspondence effect) was only observed at 100 ms in the first experiment for both types of handle, while ipsilateral inhibition was obtained when lateralized colored bars were used. Because a significant positive correspondence effect was found for graspable objects but not for lateralized bars, the attentional shift/spatial coding view is not able to completely explain our data, and therefore, the grasping affordance hypothesis remains as the most plausible explanation. The use of graspable objects (intact vs. broken handles) and the time course of facilitation observed in our first experiment and in similar studies from

other authors indicate the importance of further studies to better understand the time dynamics of facilitation/inhibition of motor responses induced by graspable objects.

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### **Compliance with Ethical Standards**

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**Conflict of Interest:** Author Ariane Leão Caldas declares that she has no conflict of interest. Author Walter Machado-Pinheiro declares that he has no conflict of interest. Author Olga Daneyko declares that she has no conflict of interest. Author Lucia Riggio declares that she has no conflict of interest.

**Ethical Approval:** All procedures performed in this study, which involved human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

**Informed Consent:** Informed consent was obtained from all individual participants included in the study.

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