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Who is more flexible?—Awareness of changing context but not working memory capacity modulates inhibitory control

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ABSTRACT

The present study examines how a person's working memory capacity (WMC) and awareness of change in context influences modulating inhibitory control. Context was manipulated by changing the predictive validity of a prime to a following target (i.e., the proportion of prime repetition) across three phases in a single-prime negative priming task. The prime was a distractor for the following target when the proportion was 25% (in the first and third phases) and a useful cue when the proportion rose to 75% (in the second phase). Participants' WMCs were measured and whether they were aware of the change of the prime-repetition proportion was determined in interviews at the end of the experiment. We found that when the stimulus-onset asynchrony (SOA) was short (Experiment 1), participants aware of the change of prime-repetition proportion showed a null negative priming effect when the contingency increased from 25% to 75%, and then rebooted the effect when it decreased back to 25%, thus indicating an ability to modulate inhibitory control as context varied. In contrast, the unaware participants kept inhibiting primes all the time. When SOA was long (Experiment 2), participants with awareness even showed a positive priming effect when the prime-repetition proportion increased. Surprisingly, participants' WMCs did not matter except for the conscious strategy used in the long-SOA condition. This is the first study simultaneously investigating how WMC and awareness can affect people's ability to modulate inhibitory control and reveals that awareness plays a more direct role in such modulation than does WMC.

1. Introduction

As a core component of executive functions, inhibition plays an important role in human adaptive behaviors. However, when context changes, previous distractors or prepotent responses that were detrimental for survival might become beneficial. Therefore, being able to release previous inhibition whenever the environment requires it is also important in order to be able to adapt to the ever-changing world. Participants' working memory capacities (WMCs) and awareness of context information have been taken as individual difference factors that influenced participants' ability to flexibly modulate inhibitory control in varied contexts in previous studies (e.g., Long & Prat, 2002; Vaquero, Fiacconi, & Milliken, 2010). However, inconsistent findings have cast doubt on the two accounts. Further, working memory capacity and awareness have never been examined together, leaving an unknown interaction possible. In our study, working memory capacity and awareness of context information are taken into consideration simultaneously for the first time to further clarify this issue.

1.1. Working memory capacity and inhibition

Past studies have shown that higher working memory capacity is related to a better ability to inhibit distractors. For example, Unsworth, Schrock, and Engle (2004) found that participants with high WMC responded faster and were less error-prone in the anti-saccade task than those with low WMC. Redick, Calvo, Gay, and Engle (2011) also found that the high WMC group was less error-prone than the low WMC group in a conditional go/no-go task.

In addition, using the Stroop task, other studies have shown positive correlation between WMC and the ability to inhibit distractors (Hutchison, 2011; Kane & Engle, 2003; Long & Prat, 2002). For instance, less Stroop interference was shown for the high WMC group than the low WMC group. As known, Stroop interference refers to the phenomenon that it takes longer time for an individual to name the ink color of a color-word when its ink color mismatches its meaning (i.e., the incongruent trial, such as RED in blue ink) than the color-word that its ink color matches its meaning (i.e., the congruent trial, such as RED in red ink). Such effect results from the difficulty to inhibit the

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automatic word-reading process (e.g., Brown, Gore, & Carr, 2002; Long & Prat, 2002; Posner & Snyder, 1975). Therefore, the more one can inhibit the semantic of the Stroop word (the distractor), the faster one can respond to the incongruent trial, leading to less Stroop interference.

Similarly, studies using negative priming tasks to measure cognitive inhibition found that the high WMC group showed larger negative priming effect than the low WMC group (Conway, Tuholski, Shisler, & Engle, 1999; Long & Prat, 2002). Negative priming refers to delayed or impaired response to a target stimulus that was previously a distractor. It is usually taken as the index of inhibition because the slower response to the repeatedly displayed stimuli is attributed to the interference of previous distractor inhibition (e.g., Dalrymple-Alford & Budayr, 1966; Houghton & Tipper, 1994; Strayer & Grison, 1999; Tipper, 2001). For example, to name the ink colors of a series of color-words, participants would respond slower to a RED in blue ink following a BLUE in yellow (i.e., the previous distractor is shown as the present target stimulus) than to a RED in blue following a GREEN in yellow (i.e., the previous distractor is unrelated to the present target stimulus). Negative priming effects are indexed by the difference in reaction times between these two types of trials. The more one inhibits the distractor, the larger the negative priming effect.

Even though there are promising studies on the relationship between WMC and inhibition, studies investigating how WMC modulates the inhibitory process in a changing context are few and inconsistent. Long and Prat (2002) first found that only participants with high WMC could modulate inhibiting the semantic of color-words in the Stroop task in different proportions of congruency (i.e., the proportion of the color-word that its color ink matched its meaning; this concept is used interchangeably with "context" in this article). The study found that high-WMC individuals showed significant Stroop interference when the proportion of congruency was high, indicating decreased distractor (semantic) inhibition, but null Stroop interference when the proportion of congruency was low. However, those with low WMC showed significant Stroop interference whether the proportion of congruency was high or low, indicating the same degree of distractor inhibition regardless of context.

To our knowledge, no other study has ever replicated such a finding. Two other studies using the Stroop task found that both high and low WMC individuals showed more Stroop interference as the proportion of congruency increased (Kane & Engle, 2003; Meier & Kane, 2013), indicating a flexibility of inhibitory control regardless of WMC. Hutchison (2011) even showed a different result to Long and Prat (2002). He found that only low WMC individuals showed high Stroop interference when the proportion of congruency was high, while high WMC individuals showed similar Stroop interference regardless of the context.

However, the above three studies also reported that participants with low WMC revealed a larger difference between congruent and incongruent trials on error rates under the high congruency condition compared to those with high WMC, indicating that the probability effect (i.e., the difference in Stroop interference or priming effects due to varied proportions of congruency) shown by low WMC individuals might be due to their shortage of ability to maintain goals (Hutchison, 2011; Kane & Engle, 2003; Meier & Kane, 2013) rather than a flexibility to modulate the degree of distractor inhibition as context varied. As we can see, the influence of WMC on the flexibility of inhibitory control is unreliable and needs to be further verified.

1.2. The impact of awareness on cognitive control

There is also evidence that conscious awareness of context-relevant information predicts a probability effect. For example, Cheesman and Merikle (1986) found that Stroop interference was sensitive to the proportion of congruency only when the prime[1] was presented long enough to be above the subjective threshold of awareness. In addition, Vaquero et al. (2010) reported participants being aware/unaware of the prime-probe contingency depended on different processes. Specifically, in a spatial cueing task, participants who could detect the contingency properly used primes to predict locations of targets, resulting in a positive priming effect (faster response to the probe display when the location of a target in the prime display was repeated in the probe display), while those who did not detect it would keep inhibiting prime displays, resulting in a negative priming effect (slower response to the probe display when the location of a target in the prime display was repeated in the probe display).

However, other studies implied something else. For instance, Crump, Gong, and Milliken (2006) found that, although participants showed various degrees of Stroop interference between high and low proportion of congruency, their estimates of proportions did not differ between these two conditions. That is, the probability effect of the Stroop interference could occur without explicit awareness of the congruency manipulation. Similarly, Blais, Harris, Guerrero, and Bunge (2012) found that the probability effect of the Stroop interference occurred no matter whether an individual was confident in his/her estimation about the proportion of congruency.

Note that the above studies made conclusions about the impact of awareness based on varying criteria or different measurements of awareness, which we thought might explain some of the inconsistency. For example, in the study of Vaquero et al. (2010), participants were classified as "aware" if their estimation of the proportion of congruency at the end of the task was close to the actual one (e.g., when the proportion of congruency was 75%, those whose estimation of proportion was above 50% would be taken as those with awareness), while the others were classified as those without awareness. In contrast, Crump et al. (2006) did not separate participants into those with and without awareness or compare the performance between those two groups. They argued that the probability effect was irrelevant to participants' awareness of contingency because their averaged proportion estimation for high-congruency condition did not significantly differ from the low-congruency one.

As for Blais et al. (2012), participants were asked to estimate the proportion of congruent trials as well as their confidence about the estimation at the end for each of the 190 blocks. Participants were classified into aware or unaware group, block by block, based on their confidence ratings since participants showed better estimation when they were confident about the estimation. However, their participants also showed significantly larger probability effects when they made the estimation about proportions of congruency than when they did not. Chances are that repeated estimations about the proportions of congruency could make all the participants sensitive to the change of the proportions of congruency to some extent and smooth the difference in awareness, leading to the absence of awareness effect.

Except for some possible confounding, the past studies usually focused on one of the two factors and never investigated the effects of them both at the same time. Lack of communication among those studies might also have limited the chance for us to explain the previous inconsistent findings. To clarify the issue, in the present study, we take these two factors into consideration simultaneously and use a procedure and task that can further reduce some possible confounding (will be specified in the following section).

1.3. The present study

A single-prime negative priming (NP) task, instead of a typical Stroop task, was used in this study. As a task to measure negative

[1] In the Stroop task used in Cheesman and Merikle (1986), a prime (a color word in white ink, e.g., BLUE) was always presented before a target (a rectangular color-patch). Participants were instructed to name the color of the target display as soon and correctly as possible.