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Working memory distortions of duration perception are modulated by attentional tags

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ABSTRACT

Recent research has shown that the contents of working memory can alter our perceptual experiences of visual matching stimuli. However, it is possible that different kinds of working memory representations may distort visual perception in different ways. In the present study, we associated working memory representations with different attentional tags and then examined their effects on perceived duration. The results showed that working memory representations prolonged apparent duration when they were tagged as a target and shortened perceived duration when they were tagged as a distractor. This is the first demonstration that attentional tags can modulate working memory effects on perceptual experience. We conclude that the influences of working memory on visual perception are determined not only by what information to be held in memory, but also by how the information is represented in memory.

1. Introduction

According to the biased competition model of attention (Desimone & Duncan, 1995), top-down modulation by working memory representations may be crucial to resolve the competition for selection between different stimuli in the visual field by biasing attention toward a memory-matching item. In line with this, previous studies have provided evidence suggesting that working memory representations can guide attentional deployment (e.g. Downing, 2000; Soto, Heinke, Humphreys, & Blanco, 2005; Soto & Humphreys, 2007) and enhance perceptual processing (e.g. Han, 2015; Pan, Cheng, & Luo, 2012; Soto & Humphreys, 2006; Soto, Wriglesworth, Bahrami-Balani, & Humphreys, 2010) in the presence of stimulus competition. Moreover, converging evidence has recently emerged suggesting that the contents of working memory can also alter the appearance of subsequently presented stimuli in the visual scene (Kang, Hong, Blake, & Woodman, 2011; Pan & Luo, 2012; Pan, Zuo, & Yi, 2013; Saad & Silvanto, 2013; Scocchia, Cicchini, & Triesch, 2013). For example, Pan et al. (2012) showed that a brief visual stimulus appears longer in duration when its color matches that held in working memory. The duration elongation effect cannot be due to the mechanism of visual priming, since mere exposure to a color cue without explicit memory requirements actually shortens the perceived duration of the matching stimulus. Thus, it has been demonstrated that the contents of working memory can prolong the apparent duration of visual matching stimuli. In this study, we investigated if different types of working memory representations influence the visual perception of temporal duration in the same manner.

It has been recently proposed that items held in working memory are given different attentional tags according to whether they function as an attentional template (Kuo & Chao, 2014). Items that serve as a template for selection are tagged with a "target tag" in working memory, whereas those that function as a template for rejection are associated with a "distractor tag". While the target items in working memory should be used to guide attention to select the matching stimuli in the scene, the distractor items in working memory should be utilized to bias attention away from the visual matching stimuli (Arita, Carlisle, & Woodman, 2012; Woodman & Luck, 2007; but see Beck & Hollingworth, 2015). It has been shown that these two kinds of working memory representations do not influence perceptual selection in the same fashion (Kuo & Chao, 2014). Thus, it is possible that they may also have different effects on perceptual experience.

In the present study, we directly addressed the question of whether attentional tags modulate working memory effects on the appearance of new sensory inputs, using psychophysical techniques to measure observers' perceived duration during working memory maintenance. Previous research regarding working memory effects on duration perception used a recognition task to ensure that participants retained the cue item in working memory (Pan & Luo, 2012). In this situation, the memory cue must be associated with a target tag. However, the effect of distractor tags in working memory is yet to be determined. Here, we used Kuo and Chao's (2014) task paradigm to manipulate attentional tags in working memory. Participants were instructed to memorize a color cue at the beginning of each trial and subsequently had to perform a duration judgment task. At the stage of memory test, they were presented with a search task instead of a recognition task. The search

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array consisted of a target and a distractor, with one matching the memorized color and the other mismatching the memorized color. The color cue held in working memory should be given a target tag when the search target matched the memorized color, and a distractor tag should be assigned to it when the search target mismatched the memorized color. Thus, this task paradigm enables us to directly compare the effects of target- and distractor-tag in working memory on the perception of duration.

It has been suggested that the perceived duration of a brief visual stimulus correlates with the magnitude of the neural responses to that stimulus in the visual cortex, with stronger neural activity corresponding to longer apparent duration (Eagleman & Pariyadath, 2009; Zhou, Yang, Mao, & Han, 2014). If subjective duration really depends on the efficiency of neural coding, the effect of working memory contents on perceived duration would be determined by whether there are any differences in the amplitude of neural activity between memory-matching and mismatching stimuli. Previous research has shown evidence suggesting that working memory representations associated with a target tag can intensify the neural responses to the visual matching stimuli (Soto, Humphreys, & Rotshtein, 2007) and lengthen their perceived duration (Pan & Luo, 2012). Accordingly, we reasoned that working memory representations associated with a distractor tag would suppress the neural responses to the matching stimuli and reduce their apparent duration.

The current study was designed to investigate if the target and distractor tags in working memory exert distinct influences on the subjective duration of visual events. Observers were presented with a color cue to hold in working memory, followed by a duration judgment task in which they had to indicate which of the two circles presented successively at the center of the screen had a longer (or shorter) duration. One of the two circles had the same color as the memory cue (matching stimulus) and the other did not (mismatching stimulus). The memory-matching and mismatching stimuli differed in objective duration on every trial. In order to assess the effects of memory contents on subjective duration, duration judgment accuracy was compared between trials on which the matching stimuli had a longer objective duration and those on which they did not. More importantly, to examine if attentional tags play a functional role in working memory effects on perceived duration, the critical manipulation was whether the color cue held in working memory was associated with a target or distractor tag.

2. Experiment 1

2.1. Method

2.1.1. Participants

Twenty-four volunteers participated for cash compensation. All of them had normal or corrected-to-normal visual acuity and normal color vision and were naive with respect to the purpose of the experiment. One participant was left out of the analyses because he made up to 50% errors in the memory task, leaving a total of 23 participants.

2.1.2. Stimuli

In the memory task, a single colored square (3.5° × 3.5° of visual angle) was presented as the memory cue, and two colored squares were simultaneously presented as the memory-guided search array, with each containing a black line inside of it (see Fig. 1). The line could be vertical, left-titled, or right-titled. In the duration judgment task, two colored circles (each 3° × 3°) were successively presented. The paired durations of the circles were 600/750, 650/812, 700/875, and 750/937 ms (all confirming to a shorter/longer ratio of 1/1.25), which were the same as those used in Xuan, Zhang, He, and Chen's (2007) study. The stimulus color was chosen randomly from a set of five colors (red, green, blue, yellow and cyan). All stimuli were presented on a gray background at a viewing distance of 57 cm.

2.1.3. Procedure and design

Participants initiated each trial by pressing the space bar. Each trial began with the display of a black central fixation cross (0.2° × 0.2°) for 1000 ms. A colored square was then presented at the center of the screen for 600 ms. Here participants were instructed to memorize the color of the square and keep it in mind throughout the entire trial. After a delay of 200 ms, two different colored circles were successively presented at the center of the screen, with an interstimulus interval of 200 ms. Immediately after the offset of the second circle, participants were asked to make an unspeeded judgment regarding which of the two circles was presented for a longer (or shorter) duration by pressing one of two possible buttons. A search task followed 500 ms after the duration judgment was completed. Here, two different colored squares (one of which matched the memorized color) were presented to the left and right side of the screen, with each surrounding a line that could be vertical, left-titled, or right-titled. Participants were required to search for the colored square that matched (target-tag block) or mismatched (distractor-tag block) the memorized color, and make a button-press response to the orientation of the line contained in that square.

The paired circles were always different from each other in color on each trial, with one circle matching the memorized color and the other mismatching the memorized color. The four duration pairs occurred with equal probabilities (i.e., 25% of all trials for each pair) and were randomized across trials. The memory-matching circle had a longer duration than the mismatching one on half of the trials (match-longer condition) and the reverse was the case on the other half (match-shorter condition). Also, the memory-matching circle was presented earlier than the mismatching one on half of the trials. These two factors varied randomly across trials. The two lines in the search task always had different orientations on each trial. There were a total of 320 experimental trials. The trials were blocked by tag type, with each block containing 160 trials of either target- or distractor-tag condition. There were two blocks each of target- and distractor-tag block, leading to a total of four blocks. The target- and distractor-tag blocks were alternated and counterbalanced across participants.

In order to eliminate the potential impact of response bias (i.e., observers may simply report the memory-matching stimulus in the duration judgment task), half of the participants were asked to indicate which of the two circles had a longer duration, and the other half were asked to indicate which had a shorter duration. Moreover, participants were never asked to report the color of a circle, but simply to indicate the temporal order of the onset of the circle (first vs. second) that was presented for a longer (or shorter) duration. There is no obvious

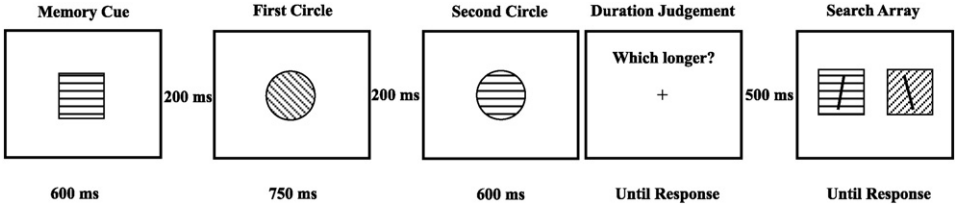

Fig. 1. Schematic illustration of the trial sequence and example stimuli in Experiment 1. The different patterns represent different colors.