Consciousness and Cognition 55 (2017) 214–222

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

Independent operation of implicit working memory under cognitive load

Eunhee Ji, Kyung Min Lee, Min-Shik Kim*

Department of Psychology, Yonsei University, Republic of Korea

ARTICLE INFO

Keywords:
Explicit working memory
Implicit working memory
Visual search
Spatial working memory
Consciousness

ABSTRACT

Implicit working memory (WM) has been known to operate non-consciously and unintentionally. The current study investigated whether implicit WM is a discrete mechanism from explicit WM in terms of cognitive resource. To induce cognitive resource competition, we used a conjunction search task (Experiment 1) and imposed spatial WM load (Experiment 2a and 2b). Each trial was composed of a set of five consecutive search displays. The location of the first four displays appeared as per pre-determined patterns, but the fifth display could follow the same pattern or not. If implicit WM can extract the moving pattern of stimuli, response times for the fifth target would be faster when it followed the pattern compared to when it did not. Our results showed implicit WM can operate when participants are searching for the conjunction target and even while maintaining spatial WM information. These results suggest that implicit WM is independent from explicit spatial WM.

1. Introduction

What is the function of consciousness on working memory (WM)? Previous researchers have regarded consciousness as essential for WM operation (Baars & Franklin, 2003; Baddeley, 1992; Cohen, Cavanagh, Chun, & Nakayama, 2012), given that WM is involved in maintaining mental representations and operating executive functions such as cognitive control, inhibition, and computation (Baddeley, 2003, 2012; Hassin, Bargh, Engell, & McCulloch, 2009; Kieras, Meyer, Mueller, & Seymour, 1999; O'Reilly, Braver, & Cohen, 1999; Schneider, 1999). Researchers have also assumed that consciousness is closely bound to the interaction between WM and attention (Baars & Franklin, 2003, 2007; Baddeley, 1992; Chun, Golomb, & Turk-Browne, 2011; Desimone & Duncan, 1995). However, this view has been challenged by recent studies showing WM can operate without conscious awareness and intention (Hassin et al., 2009; Pan, Lin, Zhao, & Soto, 2014; Soto, Mantyla, & Silvanto, 2011).

The existence of implicit WM was demonstrated more directly through a new WM paradigm (Hassin et al., 2009). In this paradigm, participants were asked to discriminate dots, which appeared sequentially in a grid on the screen, by reporting whether the dot was filled or non-filled. Hassin and colleagues hypothesized that if an individual could extract the pattern of sequentially presented dots, response time (RT) to the fifth dot would depend on whether the fifth dot was presented at the expected location or not. They also assumed that if the pattern extraction effect could be observed even though participants were not aware of the pattern, this would indicate that WM could work unconsciously. Indeed, RTs to the fifth dot were faster when it followed a pre-determined pattern compared to when it was presented at an unexpected location. Moreover, participants did not notice that some pattern sets existed behind the appearing stimuli sequence.

Although Hassin et al. (2009) suggested that implicit WM can conduct similar functions with those of explicit WM, the

* Corresponding author at: Department of Psychology, Yonsei University, 50, Yonsei-ro, Seodaemun-gu, Seoul, Republic of Korea.
E-mail address: kimm@yonsei.ac.kr (M.-S. Kim).

http://dx.doi.org/10.1016/j.concog.2017.08.014
Received 27 February 2017; Received in revised form 18 August 2017; Accepted 30 August 2017
Available online 08 September 2017
1053-8100/

relationship between implicit WM and explicit WM is not clear yet. The prior question we need to answer is what distinguishes implicit WM from explicit WM. The focus of the present study was to determine whether the operation of implicit WM is independent of explicit WM in terms of cognitive resources. We hypothesized that if implicit WM can work under cognitive resource limitation of explicit WM, participants could simultaneously perform pattern extraction while conducting additional cognitive task related to explicit WM without interference.

Given that it is necessary for pattern extraction to maintain locations of dots, compute the relationship of dots, and control selective attention to expected location, the type of information involved in the new WM paradigm (Hassin et al., 2009) might be visual and spatial. Cognitive psychologists have acknowledged that visual WM is divided into spatial WM and non-spatial WM (Baddeley & Logie, 1999; Courtney, Petit, Maisog, Ungerleider, & Haxby, 1998; Jonides et al., 1993) and visual search process is implicated with spatial WM (Kim & Cave, 1995; Treisman & Gelade, 1980). Furthermore, it was found that maintaining spatial information in WM or using executive WM interferes with visual search (Han & Kim, 2004; Oh & Kim, 2004; Woodman & Luck, 2004), since attention is highly related with WM (Awh & Jonides, 2001; Baars & Franklin, 2003; Baddeley, 1992; Chun et al., 2011). Therefore, we selected a visual search task and a spatial WM task as additional tasks, given that the content of information held in WM plays a critical role in examining the capacity between WM and visual search (Martini, Sachse, Furtner, & Gaschler, 2015).

As a manipulation of cognitive resource competition, we used a conjunction search task instead of a simple discrimination task. In the original version of Hassin et al. (2009)'s implicit WM paradigm, participants had to discriminate one stimulus at a time; consequently, visual focal attention was fixed to one location at a time and participants did not need to ignore other input. On the other hand, in a visual search task, participants have to find a target among diverse distractors. Therefore, in a conjunction search task, participants give priority to finding the target while ignoring distractors even if the task follows a pre-determined pattern. If implicit WM uses same resources of explicit WM, visual search might lead to interference in the operation of pattern extraction and vice versa, resulting in competition for common resources (Kim, Kim, & Chun, 2005; Oh & Kim, 2004; Pashler & Sutherland, 1998; Silk, Bellgrove, Wrafter, Mattingley, & Cunnington, 2010; Woodman & Luck, 2004). On the other hand, if implicit WM is a separate mechanism from explicit WM in terms of not only consciousness but also cognitive resources, pattern extraction might not be contingent on additional visual search task.

In addition to a visual search, we also manipulated WM load in Experiment 2. Even though searching a target among distractors was related to spatial WM, its effect would not be enough to interfere with the operation of implicit WM. To rule out this alternative explanation, we examined whether the effect of pattern extraction could survive under exhausted cognitive resources by adding an explicit spatial WM load.

2. Experiment 1

In Experiment 1, we asked the following question: could participants draw the pattern behind search displays presented in serial order and use it during a visual search? To address this question, participants were asked to search the target (the letter "T") among distractors (the letter "L") as quickly as possible. Five visual search tasks were conducted in consecutive order in one trial, and each trial was affiliated with the pattern set condition, the yoked broken pattern condition, the yoked control condition, and the random condition. The following key measure would provide this question: was search RT to the fifth search display faster when it followed a pre-determined pattern than when it did not follow the pattern?

2.1. Method

2.1.1. Participants

Undergraduate students (N = 23) volunteered and received credit in their psychology courses. Participants with normal or corrected-to-normal vision were recruited and asked to provide written consent to participate.

2.1.2. Stimuli and apparatus

Visual search displays were presented on an Intel core Duo level computer and a 23-in. LCD monitor with a resolution of 1920 × 1080 pixels and a 60-Hz refresh rate. The viewing distance was about 57 cm, and a pixel size was about 0.03°. The experiment was programmed in Matlab (R2010a, 32-bit) using Psychophysics Toolbox Extension 3.0 (Brainard, 1997).

The whole grid (40 × 30) was displayed on the computer screen and the size of a cell was 0.68° × 0.67°. Visual search display occupied 4 × 4 grid where a target and three distractors were on the corner of the grid respectively. Search stimuli were 0.46° × 0.45° and each one was 1.43° from the center of search display. The target "T" was tilted 90° to the right or to the left, and the distractor "L" was randomly rotated clockwise 0°, 90°, 180°, or 240°.

2.1.3. Procedure

Upon arriving to the laboratory, participants signed a consent form and then were told about the main search task. They had to find a "T" among three "L's" in a 2 × 2 array display as soon as possible and then discriminate the orientation of a tilted "T". If the target "T" was tilted to the left, participants pressed the key ' > ', and if it was tilted to the right, they pressed the key '?'. A short auditory feedback was followed only after erroneous response. A moving and changing visual search display appeared one at a time and each trial consisted of five of these displays. There was neither a fixation point of visual search display nor any frame to demarcate search displays. Participants began the trial by pressing the spacebar key at a self-paced manner. They had to respond within 10 s, and after each response, the search array disappeared for 200 ms before the next search array. If participants made no