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A model of how working memory capacity influences insight problem solving in situations with multiple visual representations: An eye tracking analysis

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ABSTRACT

Insight problem solving, which involves the restructuring of problems and insights, should be closely related to attention and working memory (WM). This study aimed to employ eye-tracking techniques to understand the process by which attention and WM capacity may influence insight problem solving when situations with multiple visual representations are employed. Fourteen graduate students participated in a 70-minute experimental session in this study. The adapted situation-based creativity task (SCT) and the adapted situation-based WM task (SWMT) were employed to measure WM capacity and insight problem solving. Using situation-based visual WM tasks and insight problem solving the findings of this study suggest the following. First, fixation, gaze duration, and saccades to targets are effective eye movement indicators that can aid in the understanding of the cognitive processes of WM and insight problem solving. Second, attention, eye movements, and WM capacity interactively influence insight problem solving, and that influence varies with WM capacity and the insight stage. Accordingly, we propose three stages of insight processes based on eye movements.

1. Introduction

Insight is the process by which a problem solver reconstructs a problem and suddenly comes up with a solution after systematic searches for solutions have failed. Moreover, insight is usually sporadic and unpredictable (De Dreu, Baas, & Nijstad, 2008). In cognitive psychology, many researchers focus on the process of insight by studying insight problem solving because this approach enables researchers to experimentally examine the process of insight within a relatively short time period (Abraham & Windmann, 2007). Insight problems typically involve an open problem and closed solution, and they also involve restructuring the problem before the problem can be solved (Abraham & Windmann, 2007).

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Working memory (WM) is considered an online cognitive process through which the learner acquires and processes new information to solve the encountered problem (Baddeley & Logie, 1999; Cowan, 1999). WM capacity is also considered as a prerequisite for cognitive flexibility, strategic planning, and the speed with which information is transferred to long-term memory (Baddeley, 2000; Cowan, 2010; Dietrich, 2004). WM also allows one to hold in mind knowledge that is relevant to solving a particular problem (Dietrich, 2004). Study findings have suggested that WM span is related to the ability to solve difficult problems (Song, He, & Kong, 2011) and that WM capacity benefits creative insight because it enables the individual to maintain focused attention on the task and prevents undesirable mind wandering (De Dreu, Nijstad, Baas, Wolsink, & Roskes, 2012). Thus, WM capacity should have a strong influence on insight problem solving. Previous related studies, however, have seldom measured WM and insight problem solving using tasks that share similar but complex contexts in which multiple visual objects are presented (i.e., few studies have measured WM that required some combination of instruments and then measured how participants employed these instrument combinations to solve subsequent insight problems in which more than 10 objects were presented). Will the relationship between WM and insight problem solving be different in such a complex situation? This study seeks to answer that question.

Moreover, although a few studies have investigated the relationship between WM and insight problem solving, few researchers have examined the process by which WM influences insight problem solving using eye movements. Numerous researchers since the 1970s have developed methods of recording eye movements to further the understanding of cognitive processes during learning. Specifically, eye tracking has been useful in revealing the on-line process of diagram-based problem solving (Grant & Spivey, 2003). Recently, eye tracking has also been applied to further understanding how learners interact with multiple representations and how their attention to different representations influences learning (van Gog & Scheiter, 2010).

Based on the merits of the eye tracking technology, this study sought to use eye movement data to understand the process by which WM capacity influences insight problem solving that involves the employment of multiple visual representations. We simultaneously investigated whether individuals with different WM capacities and insight problem solving abilities would show different eye movement patterns, by which a model that depicts the relationship between WM capacity, eye movements, and insight problem solving would be proposed.

2. Definitions and theories of WM and insight problem solving

2.1. WM

According to Baddeley's (2003) multicomponent model of WM, WM is composed of the following four subcomponents: (1) the central executive, which is an attention-controlling system that is responsible for directing attention to relevant information, suppressing irrelevant information, and coordinating two slave systems, i.e., the phonological loop and the visuospatial sketch pad; (2) the phonological loop, which consists of a phonological store that can hold memory traces for a few seconds and an articulatory rehearsal process that is analogous to subvocal speech; (3) the visuospatial sketch pad, which handles visual images and spatial information; and (4) the episodic buffer, which is a limited-capacity store that binds information together to form integrated episodes that is assumed to be under the attentional control of the executive.

The other commonly cited WM theory is Cowan's (1999) embedded-process model. This model assumes that WM is a part of long-term memory and that the memory system is operated via the interactions between attentional and memory mechanisms. In addition, WM is organized into two embedded levels (Cowan, 1999). The first level consists of activated long-term memory representations. Information in the memory system can be held in activated or non-activated states; when in non-activated states, these elements represent long-term memory (LTM). The second level is the focus of attention. Attentional resources are used to retrieve information from LTM in to meet current needs. Moreover, activated units can arise from multi-modal sensory input and semantic and episodic information from LTM. Though these representations may or may not be in conscious awareness, they are readily accessible for use when necessary. A portion of these items can further become the focus of attention (Cowan, 2010). Cowan also suggested that deliberate actions are based on the contents of the focus of attention. Accordingly, WM is used to indicate a functional level at which activated memory, the focus of attention, and central executive processes work together to keep items in mind and thus address various cognitive tasks.

2.2. Insight problem solving

Wakefield (1989) defined four types of problems: (1) closed problems with open solutions; (2) open problems with closed solutions; (3) open problems with open solutions; and (4) closed problem with closed solutions. In an open problem, the valid solution path is not clearly defined; the solver needs to discover it. Conversely, in a closed problem, the information presented is quite clear and logically entails the solution. Of these types of problems, "open problems with closed solutions" are the classic insight problems. Insight tasks typically require a mental restructuring of problem information that leads to a sudden understanding of the solution to the problem (Bowden, Jung-Beeman, Fleck, & Kounios, 2005; De Dreu et al., 2008). Pretz, Naples, and Sternberg (2003) also proposed that problems can be divided into two categories: well- and ill-defined. In a well-defined problem, the problem is presented with the expectation that the current state, goal state, and operators will be sufficient to allow steady progress toward the goal. In an ill-defined problem, uncertainty exists not only in whether the goal will be reached but also in how to conceive the current state, goal state, and operators. Moreover, an ill-defined