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Problem format and updating function domains in solving of area problems

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ABSTRACT

We investigated whether individual differences in visual updating function are important in solving arithmetic word problems. First, undergraduate and graduate students ($n = 47$) solved area word problems, some presented with extraneous information. We measured several components of reading time for the problems (e.g., integration time) and tested participants' updating functions in the phonological and visual domains. The results indicated that a stronger phonological or visual updating function reduced the effect of extraneous information on integration time, showing that both phonological and visual updating contributed to the integration process. Second, participants ($n = 49$) solved area problems presented in a figure format. The results suggested that only the visual updating function made a significant contribution to reducing integration difficulty. We infer that individual differences in the visual updating function are important to arithmetic problem solving when the category of problem or problem format requires problem-solvers to manipulate visual information.

1. Introduction

1.1. Working memory and arithmetic word problem solving

A large body of research has shown that working memory is an important cognitive component in solving arithmetic word problems. A relationship between individual differences in working memory capacity and performance on arithmetic word problems has been reported (e.g., Andersson, 2007; Fuchs et al., 2010; Lee, Ng, Ng, & Lim, 2004; Meyer, Salimpoor, Wu, Geary, & Menon, 2010; Swanson, 2006). To solve an arithmetic word problem, problem-solvers must carry out multiple processes: they must read the problem, store the relevant information, make a plan for the solution, and perform calculations according to the plan. Working memory is used as a mental workspace for all these processes in word problem solving. It is important to explore how individual differences in working memory relate to arithmetic word problem solving.

According to the three-component model (Baddeley, 1986), working memory involves two sub-systems: a phonological loop, which stores verbal information, and a visuo-spatial sketchpad, which houses visual information. These two components are coordinated by the central executive system, which is a supervisory system concerned with attention. On the basis of this three-component model of working memory, the question of which components are important to solve word problems has previously been tackled.

Several studies have revealed the importance of the central executive system for arithmetic word problem solving (Andersson, 2007; Fuchs et al., 2010; Lee et al., 2004; Swanson, 2006; Swanson & Sachse-Lee, 2001). Swanson (2004) reports that the central executive contributes to accuracy in arithmetic word problem solving when phonological processing, fluid intelligence, and reading comprehension are controlled for. Furthermore, Lee et al. (2004) demonstrate that both the phonological loop and the visuo-spatial sketchpad contribute to performance on arithmetic word problems via literacy and performance IQ, respectively. Meanwhile, the central executive contributes to performance on this task both directly and indirectly. These studies thus indicate that the central executive system plays an important role in word problem solving.

Previous studies, however, have not provided clear evidence on the specific contribution of the central executive to arithmetic word problem solving, because the central executive seems to have multiple functions (Baddeley, 1996; Miyake et al., 2000). Miyake et al. (2000) provide evidence that the functions of the central executive include at least three executive functions, described as inhibition, switching, and updating. Inhibition is the ability to inhibit dominant, automatic, and prepotent responses. Switching is the ability to switch back and forth flexibly between tasks or mental sets. Updating is the ability to monitor incoming information for relevance to the task at hand and then appropriately update by replacing old, no longer relevant information with new, more relevant information. The relationships between these central executive functions and performance in arithmetic word problem solving have been investigated. Agostino, Johnson, and Pascual-

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Leone (2010) report that updating proficiency is the best predictor of accuracy in arithmetic word problem solving, based on structural equation modeling. Passolunghi and Pazzaglia (2005) also provide evidence that the updating function is involved in the process of solving arithmetic word problems. They demonstrate that children who exhibit better mathematical performance also exhibit a higher updating performance. These studies suggest that the updating function is most important of the three executive functions in solving an arithmetic word problem.

1.2. Relationship between the updating function and arithmetic word problem solving

Although the importance of the updating function in solving arithmetic word problems has been revealed, it has not been clarified which phase of word problem solving the updating function relates to. Problem-solvers must execute four different phases to solve an arithmetic word problem (Mayer & Hegarty, 1996). On this model, solving an arithmetic word problem comprises a translation phase, an integration phase, a planning phase, and an execution phase. The most difficult and important phase seems to be the integration phase (Hegarty, Mayer, and Green, 1992; Kintsch, 1992; Mayer & Hegarty, 1996; Polya, 1957). First, problem-solvers carry out a translation phase, in which they translate each statement in the problem into a mental representation. In the subsequent integration phase, problem-solvers must integrate each representation into a problem model. According to the problem model employed, problem-solvers then formulate numerical expressions and calculate the value of these expressions to solve the problem. Cummins, Kintsch, Reusser, and Weimer (1988) report that most errors in word problems are due to inadequate integration of the problem in the integration phase. This finding suggests that whether a problem-solving attempt is successful or not depends on the quality of the solver's problem model.

In addition, another piece of evidence regarding the importance of the integration phase is provided by Muth (1984, 1992), who presented word problems including extraneous information, which was unnecessary to solve the problem, to sixth-grade children. Results from these studies reveal that even children who can solve a problem that includes no extraneous information are likely to fail in solving a problem with extraneous information. Although extraneous information does not change the syntactic complexity or the expression of a problem, it increases the difficulty of the integration process. These findings suggest that the difficulty of integration affects performance in word problem solving. That is, the integration process is important for success in arithmetic word problem solving.

During the integration process, problem-solvers should update the information they have stored in working memory in order to create a problem model (Kintsch, 1992). Indeed, Mori and Okamoto (2017) demonstrate that the updating function of working memory is related to the integration process in word problem solving. They conducted experiments to examine the relationship between individual differences in the updating function and the effect of extraneous information in word problem solving, in which they measured solution times corresponding to each of the four solving phases for word problems presented with and without extraneous information. The results indicate that the effect of extraneous information is to increase integration time, but that this effect is weaker in high-updating-performance problem-solvers than in low-updating-performance problem-solvers. This result indicates that a strong updating function reduces the difficulty imposed by extraneous information, and thus that the updating function plays an important role in the integration process of arithmetic word problem solving. Furthermore, the authors report evidence from a priming paradigm, providing an explanation for the findings. Problem-solvers with a weak updating function maintain extraneous information in a highly activated state even after integration, while those who have a strong updating function construct a problem model that only includes necessary information. That is, problem-solvers who have a strong updating function can update their working memory precisely during the integration process. According to this finding, individual differences in the updating function relate to the ability to construct an appropriate problem model in the integration process.

In addition, Mori and Okamoto (2017) report that phonological updating is more important than visual updating. They used two updating tasks: a letter memory task, in which the updating function is measured in the phonological domain, and a visual n-back task, in which the updating function is measured in the visual domain. Their results indicate a significant interaction between phonological updating function performance and problem type (with or without extraneous information), but no such interaction between visual updating function performance and problem type.

Arithmetic word problem solving seems to require problem-solvers to manipulate phonologically coded information as part of the integration process, because they are presented using text. Previous studies have reported findings consistent with this hypothesis, namely that the phonological loop may relate to word problem solving performance (see Raghubar, Barnes, & Hecht, 2010, for a review). Andersson (2007), for example, demonstrates that phonological loop as measured by a digit span task, contributes to word problem solving performance in 10-year-old children. This suggests that phonological processing plays an important role in solving word problems. However, some researchers have reported that visual processing also relates to arithmetic word problem solving performance (Boonen, van der Schoot, van Wesel, de Vries, & Jolles, 2013; Hegarty & Kozhevnikov, 1999; Krutetskii, 1976). Hegarty and Kozhevnikov (1999), for example, report that frequency of schematic visualization of a problem relates to performance in arithmetic word problem solving. Their study indicates that visual comprehension of a problem relates to performance in solving it, which seems to show that visual manipulation is required for integration of the problem. Thus, based on these studies, there is a possibility that problem-solvers use the visual updating function to integrate the information provided in an arithmetic word problem. It is still a controversial question, however, whether the phonological loop or the visuo-spatial sketchpad is the more important working memory component for solving word problems. Furthermore, little is known about the role of the two domains of updating, phonological and visual, in word problem solving.

1.3. Factors relating to the dominance of each working memory domain

There are several factors that may govern which working memory domain is dominant in word problem solving. The first plausible factor is the category of problem presented. The category of problems presented in previous research might be the reason the visual updating function has not appeared to contribute to the integration process: if the problems used require problem-solvers to make particular use of phonological processing, then the visual updating function may appear not to contribute to integration. While if a word problem requires problem-solvers to manipulate visual information, the visual domain could become more important. It is also possible that visual updating function is particularly important in the integration process. On the other hand, there is a possibility that individual differences in the phonological updating function always play the most important role in the integration process in word problem solving, regardless of the category of problem.