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Effects of skill training on working memory capacity

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Abstract

In this study we examined the effects of skill training, in particular mental abacus and music training, on working memory. Two groups of participants—children who had received mental abacus training and their controls—participated in Experiment 1. All participants performed the following span tasks: forward digit span, backward digit span, non-word span, operation span, simple spatial span, and complex spatial span tasks. Children (mean age: 12 years) who had received training exhibited greater simple spatial spans, but not other spans. In Experiment 2, the same span tests were given to groups of children (mean age: 12 years) and adults (mean age: 22 years) who had received music training and to their controls. For adults, the experimental group performed better than the control group with respect to both the digit span and non-word span tests. For children, the experimental group performed better than did the control group in all of the span tests. We discuss our results in terms of the domain-specific effects of skill training on working memory.

Keywords: Phonological store; Visual-spatial memory; Mental abacus; Music training

Recently, the issue of individual differences in working memory has drawn a great deal of attention in the research community (e.g., Miyake, 2001). Many studies have found that working memory plays a significant role in the performance of many cognitive tasks and in determining individual characteristics, such as general IQ and school achievements (for a review, see Gathercole, 1999). Specifically, studies using the individual difference approach have found that working memory capacity contributes to proficiencies in language comprehension (Daneman & Merikle, 1996), solving mathematical problems (Adams & Hitch, 1997), and following directions (Engle, Carullo, & Collins, 1991). Moreover, Kyllonen, and Christal (1990) observed near-perfect correlations between working memory capacity and fluid intelligence. Very few studies, however, have investigated the source of this individual difference, which led to the main concern of the current study, i.e., finding the sources of individual differences in working memory capacity, with particular attention on the effect of skill training on the working memory capacity.

Working memory is a theoretical construct that refers to the mechanism or system underlying the maintenance and processing of task-relevant information during the performance of a cognitive task (Baddeley & Hitch, 1974; Daneman & Carpenter, 1980). Working memory allows several pieces of information to be held in mind simultaneously and interrelatedly. It is essential for complex cognitive processes, such as spoken and written language comprehension, mental arithmetic, reasoning, and problem solving (see Baddeley, 1986). Working memory is also a subcomponent of the overall memory system, allowing the temporary storage and manipulation of information necessary for complex

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tasks. In contrast to the overall system, working memory is, however, limited in both its storage and processing capacity. This key characteristic makes working memory an important topic of research from both theoretical and practical viewpoints.

Even though researchers all agree on the importance of working memory in carrying out complex cognitive tasks, there is no consensus of a clear definition for working memory. Various theoretical perspectives have been proposed. These models of working memory differ in their views of the nature, structure, and function of working memory. According to Baddeley's multicomponent model (Baddeley, 1986; Baddeley & Hitch, 1974), working memory contains a core system—the central executive—that is responsible for controlling, regulating, and coordinating the overall system. The function of the central executive is close to the function of attention. This core system is assisted by two slave systems, which have both storage and processing functions.

The first slave system, the phonological loop, deals with phonological information, including a phonological store and an articulatory process. The function of the phonological loop is to aid phonological long-term learning, as in the case of acquiring new words (e.g., Baddeley, Gathercole, & Papagno, 1998). The second slave system, the visuo-spatial sketchpad, is a system for maintaining and manipulating visual–spatial information that is responsible for visual coding and handling of spatial imagery information in analog forms. It can be further subdivided into a visual component, dealing primarily with objects and their visible features, and a spatial component, dealing with locations and movements in space. The visual–spatial sketchpad is involved in visual or spatial tasks, such as remembering shapes and colors or the location and speed of objects in space. A fourth component, the episodic buffer, was included in a recent version of the model (Baddeley, 2000, 2003). The episodic buffer is also a limited-capacity storage system that is controlled by the central executive. It provides temporary storage of information held in a multimodal code. The main function of the episodic buffer is to integrate information from various subsystems and long-term memory to form a unitary episodic representation.

Cowan's (1995) embedded-processes model of working memory focuses on the close relation between memory and attention. He has proposed a hierarchical system of memory, suggesting that short-term memory is the activated portion of long-term memory. The activation is limited in duration. Items in the focus of attention are activated continuously and are directly available in working memory. Thus, the part of pre-activated memory that is in the focus of attention is the working memory, which has limited capacity. Based on this model, working memory is a global workspace used for integrating information needed for the tasks at hand (Cowan, 1988, 1993).

The third type of working memory model is Engle's controlled attention framework. His idea is similar to Cowan's view that the working memory is an active portion of the long-term memory and is close to the controlled attention. Moreover, working memory is a unitary, domain-general system with limited capacity (Engle, Cantor, & Carullo, 1992). The main approach of this framework focuses on the individual differences. For example, Engle, Tuholski, Laughlin, and Conway (1999) demonstrated that participants' working memory capacity was related to the general factor of intelligence and domain-general ability of controlled attention. In addition, Carpenter and colleagues suggest that individual differences reflect variations in the total amount of mental resources available (e.g., Just & Carpenter, 1992) that are dynamically divided between processing and storage capacity (Daneman & Carpenter, 1980). According to these researchers, working memory is a domain-general capacity used to maintain information in the STM and is assumed to be inherently different across individuals.

Alternatively, Ericsson & Kintsch (1995) have proposed that long-term knowledge and skills provide a better account of individual differences in working memory capacity. According to this view, working memory capacity is determined by the ability to efficiently assess task-relevant information in the LTM. Moreover, extensive knowledge acquired from experience in a particular domain can be used to overcome the capacity limits of working memory. Thus, this model predicts that acquired domain-specific skills can enhance the efficiency of memory storage and retrieval. Similarly, within the connectionist framework, MacDonald and Christiansen (2002) have suggested that individual differences in performance emerge from the interaction of experience and biological factors. Any architectural changes caused by these factors would have effects on both the processing capacity of the network and the nature of the representations embodied in the network. In other words, the connectionist approach does not postulate a working memory for temporary storage and processing that is separated from the representation of long-term knowledge. Moreover, the connectionist approach provides an account of how increased processing capacity in skilled performance may be acquired through learning. Based on these two frameworks, we hypothesized that acquired domain-specific skills may enhance not only the recall of domain-specific information, such as chess positions by expert chess player (e.g., Gobet & Simon, 1996; Sarriluoma, 1989) and patient information on medical diagnosis (Groen & Patel,