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Tower of Hanoi and working memory in adult persons with intellectual disability

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Abstract

Persons with intellectual disability (ID) have been found to perform more poorly than their mental age would suggest in the visuo-spatial problem solving task Tower of Hanoi (TOH). Inefficient performance has been assumed to be related to inability to use sophisticated problem solving strategies because of restricted working memory capacity. In the present study, the TOH performance of adult persons with ID was found to be equal to that of fluid-intelligence-matched general children. However, persons with ID violated the rules of the TOH more often, and needed more trials to solve the TOH problems than the children did. Visuo-spatial and executive working memory tasks were significantly connected to the TOH performance of persons with ID, whereas phonological working memory tasks were not. Poor inhibition ability was related to the poor performance of subjects with ID in the TOH. We suggest that for persons with ID, TOH performance is determined by individual differences in fluid intelligence, controlled attention, and inhibition ability.

1. Introduction

Persons with intellectual disability (ID) have been reported to show a lag of approximately 3 years in their ability to solve the visuo-spatial problem-solving puzzle Tower of Hanoi (TOH) compared with children with the same level of general intelligence. They have been found to be more fixated on rudimentary problem-solving strategies, and to violate rules more often than control groups matched for chronological age or for mental age (Borys, Spitz, & Dorans, 1982;

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Byrnes & Spitz, 1977; Spitz, Webster, & Borys, 1982). This restriction to unsophisticated strategies has been assumed to result from a limited depth-of-search capacity which, in turn, has been assumed to be related to a deficiency in working memory (WM) capacity (Borys et al., 1982; Spitz et al., 1982). But to date, no empiric study has actually demonstrated the connection.

In the TOH, participants are asked to move disks from peg to peg in order to achieve the target configuration in a limited number of moves, while simultaneously obeying certain rules. In general populations, the TOH and its variant, the Tower of London (Shallice, 1982) have been used as measures of problem-solving ability (e.g., Anzai & Simon, 1979; Simon, 1975; Welsh, Cicerello, Cuneo, & Brennan, 1995), developmental level (e.g., Klahr & Robinson, 1981; Piaget, 1976), and executive function capacity (e.g., Lehto, Juujärvi, Kooistra, & Pulkkinen, submitted; Levin et al., 1991; Morris, Miotto, Feigenbaum, Bullock, & Polkey, 1997; Shallice, 1982). The ability to solve the TOH problems has been presumed to be determined by fluid intelligence (e.g., Duncan, Burgess, & Emslie, 1995), WM capacity (e.g., Welsh, 1991; Welsh et al., 1995), inhibition ability (e.g., Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Morris et al., 1997), or the ability for attentional control (Shallice, 1982). Despite the incoherent terminology, all the cognitive processes related to the TOH, according to modern neuropsychological tradition, reflect so-called executive functions (see Burgess, 1997, for a review). As lower-order cognitive skills, such as visuo-motor co-ordination, or spatial processing have been thought to have little impact on TOH performance (Shallice, 1982), the TOH has been generally assumed to be an executive task.

The concept of "executive functions" embraces a range of cognitive skills; but the present study is restricted to an evaluation of the relationship between the TOH and WM. Although many researchers using general populations (e.g., Welsh et al., 1995) have suggested a close connection between the TOH and WM, empiric evidence is missing. One of the best-known theories in relation to the tower-tasks is the WM framework proposed by Baddeley and Hitch (1974). It describes WM as a multi-componential system consisting of executive WM, that reflects controlled attention (e.g., Baddeley & Della Sala, 1996), and cognitive processes crucial for the TOH (Shallice, 1982). At least two subordinate "slave" components, phonological, and visuo-spatial WM, are responsible for more restricted short-term storage and processing of domain-specific information (Baddeley, 1986; Baddeley & Hitch, 1974). Many previous studies of the TOH have, in contrast to the tripartite WM framework, employed the North American theory of WM capacity (e.g., Just & Carpenter, 1992) both in ID, (Borys et al., 1982; Spitz et al., 1982), and in general populations (Welsh et al., 1995). There appears to be, however, widespread agreement that executive WM and the WM capacity are broadly equivalent (e.g., Baddeley, 1996; Just & Carpenter, 1992).

It has been suggested that the ability to solve executive tasks evolves through huge developmental increments (Levin et al., 1991). In the Tower of London task, the largest gains have been found to occur between the ages of 7 and 9 and again between 11 and 12 (Anderson, Anderson, & Lajoie, 1996). The develop-