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Brain and Cognition 56 (2004) 286–292

Brain and Cognition

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Working memory, inhibition, and fluid intelligence as predictors of performance on Tower of Hanoi and London tasks☆

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Accepted 28 July 2004
Available online 15 September 2004

Abstract

The contributions of working memory, inhibition, and fluid intelligence to performance on the Tower of Hanoi (TOH) and Tower of London (TOL) were examined in 85 undergraduate participants. All three factors accounted for significant variance on the TOH, but only fluid intelligence accounted for significant variance on the TOL. When the contribution of fluid intelligence was accounted for, working memory and inhibition continued to account for significant variance on the TOH. These findings support Duncan, Burgess, and Emslie's (1995) argument that fluid intelligence contributes to executive functioning, but also show that the executive processes elicited by tasks vary according to task structure.

Keywords: Executive function; Tower of London; Tower of Hanoi; Working memory; Inhibition; Fluid intelligence; Matrix Reasoning

1. Introduction

The term executive function (EF) is used widely by psychologists to describe a complex set of theoretically related cognitive processes. Although executive function research is prevalent in the neuropsychological literature, there is not a clear consensus regarding the definition of executive function or the component cognitive processes that are encompassed by the term (Denckla, 1996; Stuss & Benson, 1987; Welsh & Pennington, 1988). A current trend in EF research attempts to identify relations between complex, goal-directed problem-solving tasks that are assumed to measure EF and hypothesized component processes. The present study examines EF as measured by the Tower of Hanoi and Tower of London tasks, particularly as performance on these tasks is related to measures of fluid intelligence, working memory, and inhibition.

One debate in neuropsychology is whether EF can be accounted for by working memory and inhibitory processes or whether the contributions of these processes are minor relative to the overriding influence of general fluid intelligence. Pennington, Benneto, McAleer, and Roberts (1996) suggested that EF may be defined by a combination of working memory and inhibitory processes due to their contribution to a variety of EF tasks (also see Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Roberts, Hager, & Hareon, 1994). The theoretical link between inhibition and working memory is supported by neuroimaging studies suggesting that both

☆ This research was partially supported by the Veterans Administration Medical Research Division, Associate Investigator Program. The data reported here were presented at the 2003 meeting of the Rocky Mountain Psychological Association in Denver, CO. We thank Heather Coulter and Julie Harrison for their assistance in data collection.
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0278-2626/$ - see front matter
doi:10.1016/j.bandc.2004.07.003

types of processes are mediated by the prefrontal cortex (Godefroy, Cabaret, Petit-Chenal, Pruvo, & Rousseaux, 1999; Goldman-Rakic, 1987; Hasher & Zacks, 1988; Prabhakaran, Narayanan, Zhao, & Gabrieli, 2000; Ranganath, Johnson, & D'Esposito, 2003). Recent neuropsychological research suggests, however, that working memory and inhibition are only moderately correlated and that much of the variance in EF performance accounted for by these processes is unshared (e.g., see Welsh et al., 2001).

As an alternative, others have suggested that fluid intelligence may be a better predictor of EF performance. Fluid intelligence generally refers to reasoning and novel problem-solving ability and is thought to be related to metacognition (Cattell, 1971; Gray, Chabris, & Braver, 2003; Sternberg, 1985). Duncan, Burgess, and Emslie (1995) assert that fluid intelligence tasks rely on the integrity of the frontal lobes and may be the best measures of executive functioning. Neuroimaging data confirm that fluid intelligence relies on prefrontal cortex activation (Duncan, 2003; Gray et al., 2003). Rabbitt and Lowe (2000) examined the role of fluid intelligence in predicting EF performance in older adults as defined by tasks from the Cambridge Automated Neuropsychological Test Battery (CANTAB). They showed that tasks thought to involve frontal processing (e.g., spatial working memory and visual memory) no longer accounted for a significant amount of variance in EF performance when fluid intelligence was taken into account. Further study is needed, however, to determine the degree of overlap between the constructs of EF and fluid intelligence and to examine whether the relationship between these constructs extends to other EF tasks.

In sum, neuropsychological research shows that working memory, inhibition, fluid intelligence, and performance on complex problem-solving tasks such as the Tower of Hanoi (TOH) and Tower of London (TOL) all appear to rely on healthy functioning of the prefrontal cortex. Based on these findings, some have postulated that EF depends on fluid intelligence (e.g., Duncan et al., 1995), whereas others have postulated that EF depends on working memory and inhibition (e.g., Pennington et al., 1996; Roberts et al., 1994). The goal of the present study was to examine the relations among these constructs. Past research by Welsh, Satterlee-Cartmell, and Stine (1999) investigated the contribution of working memory and inhibition to performance on the TOH and TOL tasks, and results showed that several working memory and inhibition measures were related to TOL performance, but only one inhibition measure was related to TOH performance. The present study further examined the relations between working memory, inhibition, and the tower tasks, here using two working memory measures (Visual Span and Memory Cards) and two inhibition measures (Stroop Interference and Colorado Card Sort perseverative errors). Extending on the study by Welsh et al., the present study also examined the contribution of fluid intelligence to performance on the TOH and TOL using Matrix Reasoning as the measure of fluid intelligence. This allowed us to determine whether or not working memory and inhibition predicted performance on the TOH and TOL beyond that explained by fluid intelligence. Based on Rabbitt and Lowe's (2000) findings, we hypothesized that the variance accounted for by working memory and inhibition tasks would be significantly reduced or eliminated when performance on Matrix Reasoning was taken into account.

2. Method

2.1. Participants

Eighty-five college students (32 males and 53 females) participated in partial fulfillment of the requirements for an introductory psychology course. The mean age of participants was 18.84 years ($SD = 1$). Participants were first asked to fill out a consent form and a demographic questionnaire that included age, date of birth, educational history, and medical history in order to screen for serious head injuries that may interfere with performance. With the exception of Matrix Reasoning, all tasks were administered on computers. The Tower of Hanoi and Tower of London tasks were given first, with the order of these two tasks counterbalanced, followed by the Colorado Card Sort Test, Memory Cards, Matrix Reasoning, Visual Span Task, and Stroop Task.

2.2. Tasks

2.2.1. Tower of Hanoi

The computerized five-ring TOH task from the Colorado Assessment Tests (CATs) was administered following the protocol outlined in Davis and Keller (1998). Participants were instructed to move disks across three vertical pegs from a start position to a goal configuration in the fewest number of moves, with a minimum of 31 moves required. Four trials were given, each requiring that all of the disks be moved from the left peg to the right peg, with the constraints that a larger disk could not be placed on top of a smaller disk and only one disk could be moved at a time. A trial was terminated upon successful completion of the problem or 100 moves. The dependent measure of interest was the average number of excess moves (beyond the minimum of 31) across the four trials.

2.2.2. Tower of London

The computerized CATs version of the TOL was used, consisting of three 2-move items and six 3-move, 4-move and 5-move items for a total of 21 problems (see Davis & Keller, 1998). The number of pegs varied