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Executive functioning in children, and its relations with reasoning, reading, and arithmetic

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Abstract

The aims of this study were to investigate whether the executive functions, inhibition, shifting, and updating, are distinguishable as latent variables (common factors) in children aged 9 to 12, and to examine the relations between these executive functions and reading, arithmetic, and (non)verbal reasoning. Confirmatory factor analysis was used to decompose variance due to the executive and the non-executive processing demands of the executive tasks. A Shifting factor and an Updating factor, but not an Inhibition factor, were distinguishable after controlling for non-executive variance. Updating was related to reading, arithmetic, and (non) verbal reasoning. Shifting was mainly related to non-verbal reasoning and reading. However, in terms of variance explained, arithmetic and reading were primarily related to the non-executive processing demands of the executive measures. The results are discussed in light of the "task impurity problem".

Keywords: Executive functions; Inhibition; Shifting; Updating; Arithmetic; Reading; Reasoning

Executive functions (EFs) are defined as the routines responsible for the monitoring and regulation of cognitive processes during the performance of complex cognitive tasks (e.g., Lindsay, Tomazic, Levine, & Accardo, 1999; Miyake et al., 2000). In neuropsychological settings, executive tasks are often used as diagnostic instruments, and there is abundant evidence that disorders of executive control are associated with damage to the frontal lobes (e.g., Baddeley, 1996; Rabbitt, 1997, but see also Alvarez & Emory, 2006). In children, the majority of studies has been concerned with the comparison of the executive capacity of clinical and non-clinical samples (e.g., Bull & Scerif, 2001; Everatt, Warner, Miles, & Thomson, 1997; Helland & Asbjørnsen, 2002; Sergeant, Geurts, & Oosterlaan, 2002). Therefore, one aim of the current study is to examine the structure of executive functions in normal children.

In general, the study of executive functioning is far from easy. One of the fundamental problems in the measurement of executive functioning is the 'task impurity problem' (e.g., Denckla, 1994; Rabbitt, 1997). Because EFs need a task framework to become manifest, executive tasks always implicate other, non-executive cognitive abilities such as verbal ability, motor speed, or visual–spatial ability. In addition, executive tasks often require more than one EF. Because executive tasks are complex and multi-cognitive in nature (i.e., they are 'impure'), and because they differ greatly in

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their background demands (Burgess, 1997), performance on executive tasks cannot readily be attributed to the absence or presence of a given executive capacity. Likewise, when a relationship is observed between the performance on an executive task and the performance on other cognitive measures, it is unclear whether this relationship is due to the executive or the non-executive processing demands of the executive task.

The impurity and complexity of executive tasks are psychometric problems, which complicate the interpretation of findings, and thus hinder hypothesis testing. Therefore, here we examine the structure of executive functioning in normal children, while addressing the more general problem of task impurity. In addition, as a second aim, the relations of executive and non-executive performance with verbal and non-verbal reasoning ability, reading ability, and arithmetic ability are explored. Below, we first discuss the recent literature on the structure of executive functioning, and the relations of the specific EFs with reasoning ability, reading, and arithmetic ability.

1. Measurement problems and the structure of executive functioning

The term executive functioning pertains to a wide variety of conscious, deliberate, meta-cognitive processes, such as planning, organized search, impulse control, goal directed behavior, set maintenance, flexible strategy employment, selective attention, attentional control, initiation of actions, fluidity, self-evaluation, and dual task performance (e.g., Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Sikora, Haley, Edwards, & Butler, 2002; Wu, Anderson, & Castiello, 2002). Within this profusion of terms, three EFs are generally acknowledged as important, because they are lower-level (i.e., supposedly implicated in performance on complex executive tasks), and relatively well-defined: shifting, inhibition, and updating (e.g., Baddeley, 1996; Miyake et al., 2000; Rabbitt, 1997).

Shifting is defined as the ability to switch between sets, tasks, or strategies, i.e., the disengagement of an irrelevant task set, and the subsequent initiation of a new, more appropriate set. For example, in the Number–Letter task (Miyake et al., 2000), subjects need to switch between judging digits (odd vs. even) and letters (consonant vs. vowel), depending on where these symbols are located on a monitor. Several subtypes of *inhibition* have been distinguished (e.g., Friedman & Miyake, 2004; Nigg, 2000). However, in studies on executive functioning, like the present, the focus is on the ability to deliberately suppress dominant, automatic, or prepotent responses in favor of more goal-appropriate ones.[1] In the Stroop task (Stroop, 1935), for example, subjects are presented with color-words that are printed in incongruent ink colors (e.g., the word 'red' printed in green), and are instructed to name the ink color and to inhibit the automatic tendency to read the word. *Updating* is defined as the ability to monitor and code incoming information, and to update the content of memory by replacing old items with newer, more relevant, information. Updating thus concerns the dynamic, goal directed manipulation of memory content. An example of an updating task is the Digit Monitoring task (Salthouse, Atkinson, & Berish, 2003), where subjects are presented with series of digits, and are asked to respond to each third odd digit by pressing 'Z' on a keyboard, and to all other digits by pressing 'M'.

Whether theoretically distinguishable EFs are actually discernible as distinct factors in factor analysis is an important question. Most studies of executive control in children used exploratory factor analysis (EFA) to address this question (e.g., Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; Klenberg, Korkman, & Lahti-Nuuttila, 2001; Levin et al., 1991; Welsh, Pennington, & Groisser, 1991). However, the factorial solutions reported differ with respect to both the number and the interpretation of extracted factors. For instance, Levin et al. (1991) reported a solution with three factors, which the authors interpreted as 'semantic association and concept formation', 'freedom from perseveration', and 'planning and strategy'. Klenberg et al. (2001) reported a four-factor solution, with factors interpreted as 'fluency', 'selective visual attention', 'selective auditory attention', and 'simple motor inhibition'.

The variation in the results of these studies is partly due to the use of different test batteries. In addition, the wide age-ranges of the samples used in these EFA studies (e.g., 7–15 years, Levin et al., 1991; 3–12 years, Klenberg et al., 2001; 11–17 years, Anderson et al., 2001) may also constitute problem. However, a specific problem with studies that have used EFA is that the non-executive processing demands of the executive tasks may influence the factor structure. The executive demands of a task refer to the monitoring and regulatory processes that the task requires, while the *non*-executive demands of a task refer to all other abilities that are

[1] Types of inhibition that cannot be considered deliberate, such as negative priming (longer reaction times in response to recently ignored or suppressed stimuli) and reactive inhibition (tendency to suppress previous responses) are usually not regarded as executive in nature (Miyake et al., 2000).