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Short-term storage is a stable predictor of fluid intelligence whereas working memory capacity and executive function are not: A comprehensive study with Iranian schoolchildren

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ABSTRACT

The present study investigates the simultaneous relationship among short-term memory (STM), working memory capacity (WMC), executive function (EF) and fluid intelligence (Gf) across two age groups using multi-group confirmatory factor analysis (MG-CFA). A total of 356 children recruited from primary school in Tehran were tested. Gf was assessed by the four subtests of the Cattell Culture Fair Intelligence Test. Digit Span, Letter Span, and the Kim Karad Visual Memory Test were used for measuring STM. WMC was measured by Backward Digit Span, Backward Letter Span, and Counting Span. Finally, the Stroop Task, the Wisconsin Card Sorting Test, and the Keep Track task measured EF. The key results derived from the analysis of the considered four-way relationships showed that STM did predict individual differences in Gf for both age groups with the same regression value. Furthermore, the contribution of specific WMC and EF variance (with their STM component removed) changed across age demonstrating a substantial instability for these constructs.

1. Introduction

Fluid intelligence (Gf) is a complex cognitive ability that allows thinking flexibly about new problems and situations. As defined by Cattell (1971) Gf is "*an expression of the level of complexity of relationships which an individual can perceive and act upon when he does not have recourse to answers to such complex issues already sorted in memory*" (p. 99). The available evidence shows that working memory capacity (WMC) is the strongest predictor of Gf (Martínez et al., 2011; Unsworth, Redick, Heitz, Broadway, & Engle, 2009) and it has been suggested that together Gf and WMC might define "*fluid cognition*" (Blair, 2006).

Working memory capacity refers to a complex cognitive system of limited capacity that stores information while simultaneously processing the same or additional information (Cowan, 1999; Tuholski, Engle, & Baylis, 2001). Therefore, from a theoretical perspective WMC comprises (a) a short-term storage component that holds information briefly, and (b) a non-storage component responsible for further processing that is usually identified with executive function, executive control, or executive attention (Conway, Kane, & Engle, 2003). These components provide a mental workspace for maintaining and transforming the relevant information acting as a temporary bridge between externally and internally generated mental representations (Alloway, Gathercole, & Pickering, 2006).

Despite the strong relationship between WMC and Gf, the question regarding the underlying causes has been extensively debated. Studying adult samples, it has been suggested that WMC and Gf are both supported by executive control mechanisms (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle, Tuholski, Laughlin, & Conway, 1999; Kane et al., 2004).

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However, Colom, Abad, Quiroga, Shih, and Flores-Mendoza (2008) demonstrated, across three concatenated studies, that short-term storage exhausts the predictive power of WMC. This latter conclusion is also in agreement with the re-analyses of several datasets published by this research group (Colom, Rebollo, Abad, & Shih, 2006), as well as with the exhaustive study by Martínez et al. (2011).

Results are also mixed for children. Studying children from kindergarten to second grade, Engel de Abreu, Conway, and Gathercole (2010) showed that cognitive control mechanisms, rather than the storage component of working memory span tasks, are the source of the link with fluid intelligence. However, studying children with 74 months of mean age, Hornung, Brunner, Reuter, and Martin (2011) demonstrated that STM accounts for the relationship between WMC and fluid intelligence. Finally, Tillman, Nyberg, and Bohlin (2008) showed, studying children (age range 6–13 years) that both short-term storage and executive processes contribute to the prediction of individual differences in Gf.

These disparate findings suggest that the relationship among STM, WMC, executive function, and Gf may be affected by the nature of the working memory system, the observed developmental changes, or the analyzed sample. The strength of the relationships among the main components of WMC may change across the developmental process. Individuals can apply these components in different ways perhaps through learning processes (Dehn, 2008). These changes might have some impact on the relationship between WMC and cognitive abilities such as fluid intelligence. It can be assumed that performance on high level cognitive function (such as fluid intelligence) results from the complex interplay between several cognitive functions such as WMC, STM, and EF. The efficiency on these functions may change across age modifying the nature of this interplay.

Still another relevant issue refers to what the administered tests and tasks of interest are measuring. For example, the digit span task, presumably measuring short-term storage, may involve cognitive control mechanisms in children, as noted by Engel de Abreu et al. (2010). Developmental increases in STM has been shown across the childhood period (Burtis, 1982; Gathercole, 1999; Riggs, Simpson, & Potts, 2011) but there is evidence showing that the executive component of the Attention Network Test (ANT, a test battery measuring three core attention functions) does not improve significantly beyond the age of 7 (Rueda et al., 2004).

Relying on these previous findings, here we investigate the simultaneous relationship among short-term storage, executive function, working memory capacity, and fluid intelligence studying two samples of schoolchildren. The first sample comprises young children (8 yrs.) whereas the second sample comprises older children (12 yrs.). Multi-group confirmatory factor analysis (MG-CFA) was applied for testing the relationships of interest. Because of the disparate results revised above, the present study must be considered exploratory.

2. Method

2.1. Participants

Participants were 356 schoolchildren with a mean age of 10.11 (SD = 2.09). Two groups were considered: younger group (N = 168, mean age = 8.13, SD = .49) and older group (N = 188, mean age = 12.10, SD = .69). They were recruited from primary schools of Tehran and informed written consent was obtained from the schools. The chosen schools were selected for representing the varied socioeconomic areas of the city. Only children enrolled in regular school classes were asked to participate in the present study.

2.2. Measures

2.2.1. Short-term storage (STM)

STM was assessed with two tasks (digit and letter span) assessing the verbal content domain and one task (Kim Karad Visual memory Test) assessing the visuospatial domain. In *Digit and Letter Span tasks* children were required to recall, in their correct serial order, a sequence of digits or letters. These tasks consisted of 7 blocks of 3 trials each, starting with three digits and increasing up to sequences of 7 items. The criterion for moving on to the next block was correct recall of 3 trials. After the failure of 3 trials in one block, testing stopped. A correct recalled list received a score of 1 and the possible maximum score on the test was 21. The number of correct trials was the dependent measure. The Kim Karad Visual Memory Test includes a collection of 2 pictured and blank pages. Participants are shown a pictured page with 20 colored pictures arranged in a matrix for one minute. They are then given a blank page and 20 picture pieces and are instructed to recreate the first page. If participants place the pieces in the correct location and in the correct orientation, they receive full credit. If the location is correct but the orientation incorrect, they receive partial credit. The sum of scores was the dependent measure.

2.2.2. Executive function/attention

Three executive processes were measured: inhibition (Stroop task), shifting (Wisconsin Card Sorting Test), and updating (Keep Track). The Stroop task (a Persian version) consists of three parts in which 4 color (red, blue, green and yellow) names are printed in black (part one), consistent with the name (part two), and inconsistent with the name (part three). Participants were asked to name the colors. Two minutes were given to complete as many trials as possible. In part 3, participants were presented with color words using incongruent colors—for example, BLUE in yellow ink or RED in green ink. Participants were required to name the color of the stimuli. The dependent measure was the difference between naming time on incongruent trials (part 3) and naming time on congruent trials (part 2). The Wisconsin Card Sorting Test — WCST (Heaton, 1981) requires participants to match stimulus and response cards according to three alternative criteria (color, form, and number). The participant must place each response card under one of the four reference cards according to these criteria. As the test progresses, unexpected shifts in the matching rule require the participant to change his/her strategy. The children were not told how to categorize cards, but they received immediate feedback regarding whether or not they have sorted the card properly. The indicator of shifting was the number of perseverative errors (when a participant does not change their categorization strategy despite feedback indicating that it is incorrect). In order to score all the tasks in the same direction (higher scores = better performance), we reversed the scores in the WCST task by multiplying the number of perseverative errors by −1. Finally, the Keep Track