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The relationship between executive functions and intelligence on 11- to 12-year-old children

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Abstract

This study investigated the structure of the executive functions and their roles in intelligence on sixty-one children aged 11- to 12-year-old. Six executive function tasks and one intelligence test were carried out in the study. The confirmatory factor analysis has shown that the executive functions could be separated into three factors: updating, inhibition and shifting. These three factors were moderately correlated with each other, but were clearly separated. The present results were in line with previous findings from adults. There were significant correlations between measures of updating, inhibition and shifting, and intelligence. However, only the correlation between updating and intelligence remained significant when the correlations among executive functions were controlled. The study gave some theoretical support to the effect of executive functions training on intelligence and self-regulated learning.

Key words: intelligence, executive functions, children

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Many definitions and models about self-regulated learning (SRL) exist (Duckworth et al., 2009). SRL generally includes setting goals for learning, concentrating on instruction, using effective strategies to organise ideas, coding and rehearsing information for memoriziation, monitoring performance, and managing time effectively (Schunk & Ertmer, 2000). SRL draws most attention from educational psychologists. Researchers mainly focus on SRL's contribution to academic achievement and how to enhance SRL itself. *Executive functions (EFs)* are concepts of cognitive psychology. They are defined differently, and usually include updating representations of the working memory, inhibiting prepotent responses, and shifting between tasks or mental sets (Perrotin et al., 2008; Willcutt et al., 2005). Updating requires actively manipulating relevant information, rather than passively storing information in working memory. Inhibition requires stopping a response that is relatively automatic. Shifting requires changes between mental tasks, although the specific operations that need to be switched back and forth are quite different across tasks. Researchers pay attention to EFs' neural mechanisms and their relationship with other cognitive construct. EFs are the foundation of many high level cognitive functions, which include planning, decision making, metacognition, strategies, and SRL (Dawson & Guare, 2004; Garner, 2009).

There is a very close relationship between SRL and EFs (Baumeister et al., 2007; Duckworth et al., 2009). Specifically, SRL relates to updating working memory (Winne, 1996). Researcher found that working memory dysfunction was associated with deficits in self-regulated action in schizophrenia (Schmiedt, 2005). SRL also involves a substantial degree of inhibition (Bjorklund & Kipp, 1996). Inhibition is a component of self-regulation, and it relates to children's development of self-regulation (Zimmerman, 1990). Besides working memory updating and inhibition, SRL is related to shifting as well. Learners with a greater self-regulation ability can shift smoothly among different engagements (Howard-Rose & Winne, 1993). Participants who received SRL training are better at shifting in mental models (Azevedo & Cromley, 2004).

Traditional complex executive tasks, such as Wisconsin Card Sorting Test and the Tower of Hanoi task, tend to suffer from relatively low reliability and construct validity (Miyake, 2000). Many researchers tend to use relatively simple tasks to measure executive functions. When trying to investigate EFs, their structure is an important and fundamental problem. This problem has been addressed in many studies during recent decades (Norman & Shallice, 1980; Pennington & Ozonoff, 1996; Smith & Jonides, 1999). One of the most popular and convincing structures is put forward by Miyake et al. (2000). After extensive literature reviews, Miyake et al. used confirmatory factor analysis (CFA) and found that three often postulated EF latent variables – updating, inhibiting and shifting – were moderately correlated but clearly separable in college students (Miyake et al., 2000). Latent variable analysis is a powerful approach to study the organization and function of EFs as it can minimize the task impurity problem compared to using manifest variables.

EFs are generally considered to be mainly mediated by the frontal cortex of the brain. These cerebral regions are relatively immature during childhood and continue to develop in late adolescence (Segalowitz & Davies, 2004). Studies from developmental psychology and cognitive neuroscience suggest that EFs can be elicited in children as young as at the age of 6 years if suitable tasks are used (Anderson, 1998; Welsh et al., 1991). It was also found that growth spurts occur in early infancy, again around 7- to 10-year-old, with a final spurt during adolescence (Anderson, 2002).

Miyake's study about the organization of EFs was carried out on college students, the age period after the final development spurt. Developmental studies may provide valuable insights into the structure and function of EFs. Other studies indicated that EFs of 8- to 13-year-old children consisted of three interrelated factors (Lehto et al., 2003). Using CFA to investigate the structure of EFs in 9- to 12-year-old children, Sluis et al (2007) only found updating and shifting these two factors, but not an inhibition factor. The inconsistencies between these results may come from the large age span of the children.

Researchers are not only concerned about the EFs itself, but also the relationships between EFs and other high cognitive abilities, such as intelligence. Understanding the relationship between EFs and intelligence can help us understand the nature of intelligence differences.

It is generally agreed that intelligence is related to EFs (Friedman et al., 2006). Specifically, numerous studies have found moderate to strong relations between intelligence and working memory updating ability (Ackerman et al., 2005; Engle et al., 1999). The evidence comes from different subjects, tasks and research approaches. With respect to inhibition, Salthouse et al. (2003) found that inhibition was strongly correlated with intelligence in aging adults. Dempster (1991) stated that "intelligence cannot be understood without reference to inhibitory processes". As for shifting, there have been mixed results from literature, perhaps depending on the participants and tasks. While Salthouse et al. (1998) found a high correlation between shifting tasks and intelligence, other studies have found either little relation (Rockstroh & Schweizer, 2001), or a weak correlation between them (Miyake et al., 2000).

Friedman et al. (2006) systematically investigated the issue of how closely each of the several EFs is correlated to intelligence. They found that when controlling for the inter EFs correlations, updating remained strongly correlated to intelligence, but the correlations of inhibition and shifting to intelligence became less significant.

This study has two main objectives. Firstly, we examine the structure of EFs in children just after the second spurt, i.e. whether the factors of 11- to 12-year-old children's EFs are correlated with each other, but separated at the same time. Secondly, how distinguishable EFs correlate to intelligence in 11- to 12-year-old children, i.e. whether all of the three EFs correlate to intelligence when controlling for their inter correlations.

Methods

Participants

Sixty-one healthy right-handed children participated in this study (27 girls and 34 boys, age 11.88 ± 0.65 years). They were selected randomly from two Chinese schools. All participants had normal or corrected-to-normal vision, and were free from neurological or psychiatric disorders. Informed consent was obtained from participants' teacher and parents.

Stimuli and procedure

Executive tasks

Updating

The updating tasks were modifications of Chen's (Chen et al., 2008). Stimuli for the Digit 2-back task were the digits 1 to 9 with same probability. Participants responded to the present digit if it was identical to the digit two trials previously. Stimuli were presented in the center of the screen with a visual angle, approximately 2.6° vertically, and 1.8° horizontally.

Stimulus for the Figure-Position 2-back task was a green dot which appeared at 9 positions with the same probability. Participants responded to the present position if it was identical to the position two trials previously. The stimuli dots were presented with a visual angle of approximately 1.2°.

Stimuli in these two tasks were presented until the participants made a response with a random interstimulus interval of 800-1000 ms. The probability of matching and mismatching condition was 50% respectively. There were 36 trials in every task. The reaction time was the test score and it was reported as millisecond (ms).

Inhibition

The inhibition tasks were modifications of Duan's (Duan et al., 2009). Stimuli for the Digit Go/Nogo task were the two digits "1" and "9". Stimuli were presented in the center of the screen with a visual angle, approximately 2.6° vertically, and 1.8° horizontally.

Stimuli for the Figure Go/NoGo task were the two figures "triangular" and "circle". Stimuli were presented in the center of the screen with a visual angle, approximately 5° vertically and horizontally.

Stimuli in these two tasks were presented for 50 ms with a random interstimulus interval of 1000-1300 ms. During each trial, one of the two stimuli was presented, and either a response (Go) or the withholding of a response (NoGo) was required. A block consisting of 48 stimuli (50% NoGo probability) was completed in every task. The rate of commission error was the test score.

Shifting

Odd-More task/Digit shifting task was a modification of Hillman's (Hillman et al., 2006). Participants viewed a series of numeric digits (digits 1-9, excluding 5) on a black background presented in the center of the screen with a visual angle of approximately 2.6° vertically, and 1.8° horizontally. Each digit was white or green colored. In one single-trial block, participants indicated if each digit was odd or even. In the other single-trial block, participants indicated if each digit was more or less than the digit "5" using the same two response keys.

Local-Global task/Figure shifting task was revised from Miyake's (Miyake et al., 2000). Participants viewed a series of figures on a black background presented in the center of the screen with a visual angle of approximately 5.5° both vertically and horizontally. The lines of the ''global'' figure (e.g., a cross) which composed of much smaller, ''local'' figures (e.g., squares), was presented on the computer screen. In one single-trial block, participants indicated the shape of the local figure. In the other single-trial block, participants indicated the shape of the global figure using the same two response keys.

The stimuli in these two tasks were presented until the participants made a response with a random interstimulus interval of 800-1000 ms. The stimuli were grouped into three task blocks, with a brief rest period between each block. The first two blocks (i.e., single-trial blocks) contained 16 trials each on one of two simple tasks that consisted of the same colored stimuli. These blocks were counterbalanced across participants. The color of the figures indicated which task was performed in each block. The mixed block, contained 32 trials, and participants performed both tasks indicated by the color (i.e., white or green). The shift cost was then calculated as the difference between the average RT's for the blocks requiring a shift in mental set (i.e., color of stimulus changed) and the blocks in which no shift was required (i.e., the color of stimulus remained the same). The cost time was reported as ms.

Intelligence test

The test to measure intelligence is Raven's advanced progressive matrices (RAPM) which is one of the most frequently used intelligence tests (Buschkuehl & Jaeggi, 2010). There are 60 items and the instruction is in Chinese. There is no Chinese norm of this test, so the number of the correct items was the test score.

Procedure

The EF tasks were administered in small groups, of which each has approximately 6 children, and every participant finished the tasks using computer individually. Instructions and practice trials were given at the beginning of each task. Children were required to respond as correctly and quickly as possible. Total testing time, including the instructions and practice, varied between 40 and 50 minutes. The stimulus presentation, behavioral data acquisition and calculation were collected using the E-prime software system. The intelligence test was administered in groups with approximately 30 children a week after the EF tasks because of the school class arrangement.

Data analysis

The preliminary data analysis were carried out using SPSS 13.0. CFA and the structure equation model (SEM) were performed using AMOS7.0.

Results

Descriptive statistics

Data were recorded from all 61 students for each task. The means and standard deviations of the EF measures are provided in Table 1. The mean of Raven score is 49.33 with standard deviation of 7.24 in this sample.

Table 1:
Descriptive statistics for the six EF tasks

		Digit	Figure
Updating	ACC	0.83 (0.12)	0.76 (0.12)
	RT	980.544 (374.76)	995.69 (280.52)
Inhibition	CE (%)	7.00 (7.20)	20.75 (17.77)
	ACC	0.98 (0.07)	0.98 (0.07)
	RT	375.32 (62.51)	377.91 (72.13)
Shifting	Single-trial RT	648.46 (160.14)	574.53 (126.57)
	Mixed-trial RT	1216.91 (439.88)	1167.59 (520.08)
	RT COST	568.45 (338.90)	593.05 (517.62)
	Single-trial ACC	0.93 (0.08)	0.90 (0.12)
	Mixed-trial ACC	0.86 (0.08)	0.78 (0.11)

Note: RT, reaction time; ACC, accuracy rate; CE, rate of commission error. The unit of RT is ms. Means and standard deviations (in parentheses) are reported.

The correlations among EF measures and intelligence are shown in Table 2. All the correlations between the two tasks which were supposed to measure the same EF were significant (*ps* < .01). Raven correlated with all of the six EF tasks except the Local-Global task.

Table 2:
Correlations between EFs measures and intelligence

	1	2	3	4	5	6	7
1. Digit 2-back	1						
2. Position 2-back	.748**	1					
3. Digit Go/Nogo	.202	-146	1				
4. Figure Go/Nogo	.243	.032	.359**	1			
5. Odd-More	.647**	.525**	.216	.343**	1		
6. Local-Global	.377**	.304*	-.064	.141	.481**	1	
7. Intelligence	-.548**	-.393**	-.343**	-.302*	-.337**	-.203	1

Note: ** $p < .01$; * $p < .05$

Confirmatory factor analysis

Miyake's (2000) theoretical ''full, three-factor'' model used for the CFA, is elicited in Figure 1. The ellipses represent the three EFs (latent variables), and the rectangles represent the individual tasks (manifest variables) that were chosen to tap the specific EFs, as indicated by the straight, single-headed arrows. The curved double-headed arrows represent correlations between each two of the latent variables. This model depicts three latent constructs, namely, updating, inhibition, and shifting, which are assumed to be correlated but separable.

A sample of 61 participants is acceptable in CFA analysis (Tabachnick & Fidell, 2007). The full three-factor model, complete with the estimated factor loadings, is illustrated in Figure 2. The numbers next to the straight, single-headed arrows are the standardized factor loadings, and those next to the curved, double-headed arrows are the correlations between the factors.

The fit indices for this full three-factor model were all excellent. Specifically, this model produced a non-significant $\chi^2/\mathrm{df} = 1.34$, $p = 0.236$, indicating that the model's predictions did not significantly deviate from the actual data pattern. In addition, the values of the RMSEA (root mean square error of approximation) were quite low (0.075), (0.080 indicating a close fit to the data and lower values indicate better fits), whereas the NFI (normed fit index), IFI (incremental fit index), TLI (Tacker-Lewis index), and CFI

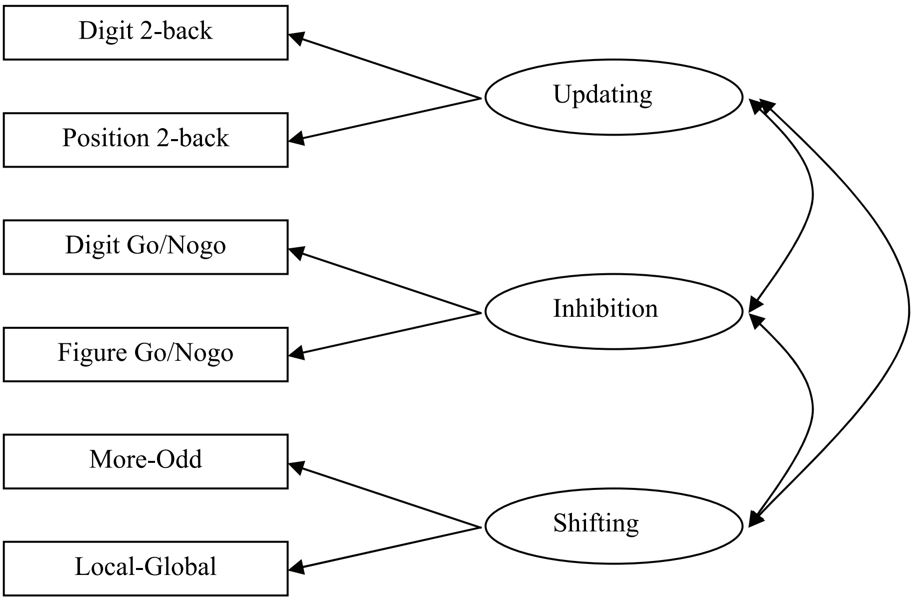

Figure 1:
The theoretical model used for confirmatory factor analysis (CFA)

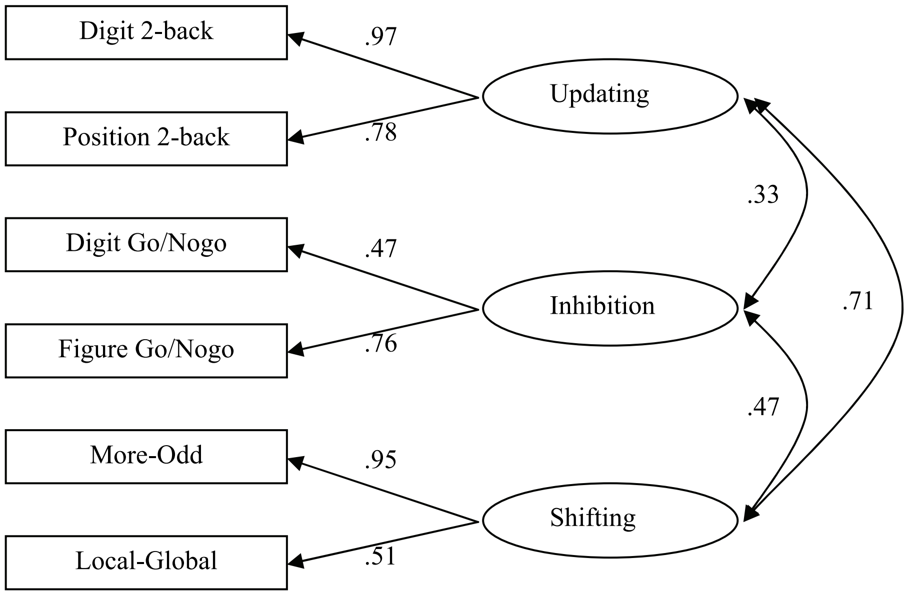

Figure 2:
The confirmatory factor analysis (CFA) model of 11- to 12-year-old children

(comparative fit index) were well above 0.90 (0.94, 0.98, 0.95 and 0.98, respectively), (values above .90 indicate good fit). Therefore, this model seems to fit the overall data quite well.

These CFA results suggest that, even though they are clearly distinguishable, the three latent variables share some underlying commonality. Thus, the three target EFs show both unity and diversity as Miyake (2000) found in the study with college students.

The relationship between executive function and intelligence

The structure equation model (SEM) of the relationship between EF and intelligence is shown in Figure 3. The path coefficient between updating and intelligence is significant, indicating that they share about 35% variances, $p < .01$; that between inhibition and intelligence is marginally significant, indicating that they share about 19% variances, $p < .1$, and that between shifting and intelligence is not significant, indicating that they only share about 7% variances.

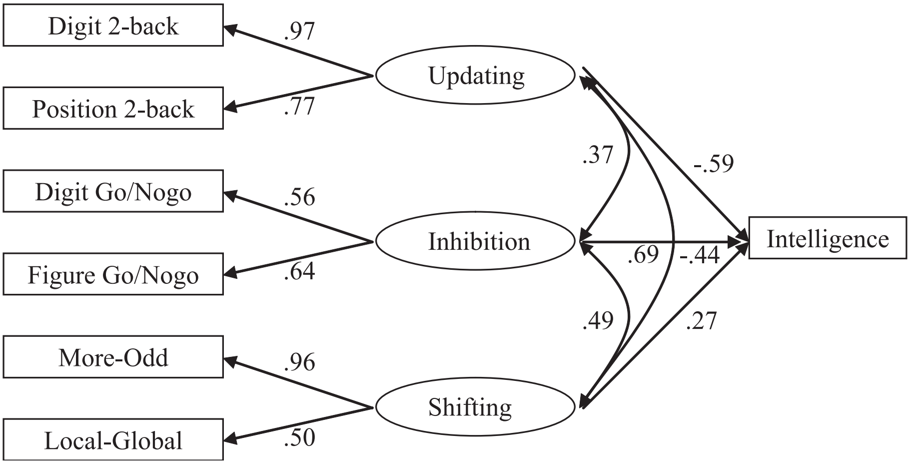

Figure 3:
The structure equation model (SEM) of the relationship between EF and intelligence

Discussion

In this article, we reported an individual difference study that examined the organization and roles of three often-postulated EFs – updating, inhibition, and shifting – at the level of latent variables, rather than at the level of manifest variables (i.e., individual tasks). In the study we used CFA to specify the structure of EF in 11- to 12-year-old children. The EF of 11- to 12-year-old children could be separated into, updating, inhibition and shifting, three factors. We also examined the extent to which updating, inhibition, and shifting are correlated to intelligence measures by using SEM. There were significant correlations between measures of these three factors and intelligence, and only updating and intelligence correlated significantly when the correlations among EFs were controlled.

The results of the correlation and CFA analysis have indicated that the six EF manifest measures succeed in tapping the three latent variables respectively. We only tested whether the Miyake's model was suitable for 11- to 12-year-old children, and the interpretations of the CFA results clearly showed that the three factors of EFs (i.e., updating, inhibition, and shifting) were moderately correlated with each other, but were clearly separated at the same time. These results were in agreement with Lehto (2003), who found similar results with 8- to 13-year-old children employing quite different tasks. These three components were also clearly separated in adults. This meant that children as young as 11- to 12-year-old were mature enough to show the EFs' structure, although Miyake (2000) pointed out that the degree of separability of EFs might be less pronounced among children. Considering the important role of frontal lobe in the function of human behavior, these results seem to suggest that 11- to 12-year-old children's brains, especially frontal lobes, were well developed to perform these higher level cognitive activities.

The age of 11- to 12 years had been identified as highly significant period for the development of EFs. All of the functions played a significant role in SRL (Duckworth et al., 2009). EFs predicted school achievement and learning-related classroom behaviour (Brock & Rimm-Kaufman, 2009). EFs training could improve students' learning and help students with learning disabilities (Parker & Boutelle, 2009). The results from this study seem to support the EFs coaching effect on the children's SRL development.

Correlation analysis showed that all of the EF measures correlate with intelligence, except for the Local-Global task. The possible reason for the non-significant correlation between Local-Global task and intelligence was the quite large standard deviation in this task. Further analysis indicated that these three EFs were correlated to intelligence in 11- to 12-year-old children differently, with the updating most closely correlated to intelligence. SEM revealed that when inter-EFs correlations were considered, the correlations between updating and intelligence measures were undiminished, but the correlations between inhibiting and intelligence and between shifting and intelligence were no longer significant. Intelligence measures shared about 35% variances with the updating, but only 19% with the inhibiting and only 7% with the shifting. These results suggested that the correlations of inhibiting and shifting with intelligence measures were due to the variance they shared with the updating. These findings are consistent with Friedman (2006).

The strong correlation between the updating and intelligence was in accordance with numerous findings of the close association between the intelligence and working memory (Engle et al., 1999; Gray et al., 2003). These results emphasized the important role of updating abilities in traditional understanding of intelligence. The weak to nonexistent correlations between intelligence and the other two EFs, particularly the shifting, may seem to be surprising at first sight. However, most of the evidence for significant correlations between these EFs and intelligence came from studies of special populations, such as clinical, gifted, and aging (Duan et al., 2009; Salthouse et al., 1998).

It is important to point out that the current data was based on a restricted sample of 11- to 12-year-old children. Therefore, the results may not be completely generalised to more cognitively diverse samples, such as those that include younger children, elderly adults, or neurologically impaired participants. The present research had important limitations as other correlation studies did. There were some variables that could not be randomized. Although the fit indices for the model were all excellent, they could not lead to causation.

The present findings from 11- to 12-year-old children were in agreement with contemporary views as to the simultaneous unity and diversity of EFs. The current finding that only the updating was related to intelligence suggested that current measures of intelligence were lacking some basic functions such as inhibition and shifting, as suggested by others (Ardila et al., 2000; Friedman et al., 2006). The structure of EFs and the relationship between EFs and other cognitive abilities appeared to change across the life time course. It would be worthwhile to extend this work with different age groups in order to address developmental issues more adequately. Considering the relationship between EFs, intelligence and SRL, it would be interesting if future studies employed cross-sectional designs and investigated the effectiveness EFs training on the development of the children's intelligence and SRL.

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