Investigating the links between the subcomponents of executive function and academic achievement: A cross-cultural analysis of Chinese and American preschoolers

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A R T I C L E   I N F O

Article history:
Available online 15 January 2011

Keywords:
Executive function
Cross-culture
Achievement
China
Working memory
Inhibition
Attention control

A B S T R A C T

Little is known about how components of executive function (EF) jointly and uniquely predict different aspects of academic achievement and how this may vary across cultural contexts. In the current study, 119 Chinese and 139 American preschoolers were tested on a battery of EF tasks (i.e., inhibition, working memory, and attentional control) as well as academic achievement tasks (i.e., reading and mathematics). Results demonstrate that although working memory performance in both cultures was comparable, Chinese children outperformed American children on inhibition and attentional control tasks. In addition, the relation between components of EF and achievement was similar in the two countries. Working memory uniquely predicted academic achievement, with some intriguing patterns in regard to tasks requiring complex processing. Inhibition uniquely predicted counting but did not uniquely predict calculation. Attentional control predicted most aspects of achievement uniformly and was the most robust predictor for reading in both countries. In sum, the data provide insight into both cultural variability and consistency in the development of EF during early childhood.

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Introduction

Previous research has shown dramatic differences between Asian and North American children's executive function (EF) (Oh & Lewis, 2008; Sabbagh, Xu, Carlson, Moses, & Lee, 2006). For instance, in Sabbagh et al. (2006) study, where 109 children in China and 107 in the United States performed a battery of EF and theory-of-mind tasks, the Chinese students were found to outperform their American counterparts on all EF tasks but not on theory-of-mind tasks. The current study explores the specificity of such Asian advantage in the relation between various components of EF (inhibition, working memory, and attentional control) and how they relate to (and differentially predict) academic achievement.

The first aim of this study was to investigate cultural differences in the three common components of EF, particularly inhibition and working memory because they have been regarded as the most critical components of EF (e.g., Garon, Bryson, & Smith, 2008). The second aim was to investigate links between Chinese and American preschoolers' EF and their math and reading achievement. In addition to higher performance on EF tasks, Asian children have been shown to have advantages over their North American counterparts in early math abilities such as counting, place values (Miller & Stigler, 1987; Miura, Chungsoon, Chang, & Okamoto, 1988), calculation, and mental mathematics (Brenner, Herman, Ho, & Zimmer, 1999; Cai, 1995; Geary, Bow-Thomas, Fan, & Siegler, 1993). However, to our knowledge, no studies to date have investigated the relations between East Asian children's EF and their math achievement. In addition, although it has been suggested that EF is more strongly associated with mathematics than with English reading achievement in general (Blair & Razza, 2007; Ponitz, McClelland, Matthews, & Morrison, 2009), less is known about how the components of EF link to reading achievement. Thus, it is of particular interest to compare the links between EF and reading English with links between EF and reading Chinese.

Understanding these associations can help to determine the extent to which particular components of EF contribute to Asian children's superior academic achievement. Our study includes samples of preschoolers from two nations: China and the United States. Mathematics, reading (e.g., Rittle-Johnson & Siegler, 1998), and EF skills (e.g., Diamond, Prevor, Callender, & Druin, 1997) undergo dramatic changes during the preschool period. Using a cross-cultural perspective to examine the links between EF and achievement provides insight into the shared ontogenetic organization of these abilities and also describes the universality versus cultural specificity of the associations. Therefore, we have examined how components of EF jointly and uniquely predict various aspects of math and reading achievement.

Components of EF and cultural differences

Although well studied in the adult literature, little is known about the construct of EF during early childhood. Some researchers have suggested that three distinct components comprise EF: inhibition, working memory, and attentional control (i.e., resistance to distracters or the ability to ignore irrelevant stimuli) (e.g., Bronson, 2000). Many studies have used the word shifting as the third component of EF (e.g., Miyake, Friedman, Emerson, Witzki, & Howerter, 2000) and have differentiated two kinds of shifting, attention shifting and response shifting (Rushworth, Passingham, & Nobre, 2002), based on whether the shifting involves selecting aspects of a stimulus or requires motor responses. Both kinds of shifting rely heavily on other EF components (Deák, 2003). Attention shifting, in particular, “is intimately tied to the development of attention and other EF components” (Garon et al., 2008, p. 48). Thus, in the current article, we chose to focus on the three most basic components of EF: inhibition, working memory, and attentional control.

We define EF as separate components operating together in response to academic and behavioral demands requiring self-regulation. We view EF as the set of complex cognitive skills (i.e., inhibition, working memory, and attentional control) involved in controlling, directing, and planning cognition, emotion, and behavior (Blair, 2002; McClelland, Cameron, Wanless, & Murray, 2007). Some other studies have argued that all of these components are highly correlated with each other and are essentially a single component during early childhood (Wiebe, Espy, & Charak, 2008). Our first objective was to examine these components of EF and their interrelations cross-culturally, focusing on examining the...
specificity of the Asian advantage with respect to various aspects of EF. As we will show, working memory is implicated in all three components, and an important part of this aim is examining the extent to which attentional control and inhibition tasks rely on working memory.

**Working memory**

Working memory allows one to hold representations in mind for a delayed period of time; it is often conceptualized as being composed of a central executive system and domain-specific short-term storage systems (Baddeley, 2002). It is an essential component of EF because for children to successfully carry out a task, they must perceive and maintain information as they perform. This might be particularly true for carrying out more complicated manipulations such as calculating with numbers and symbols (Espy et al., 2004). As a result, performance on many tasks may be associated with and also bound by working memory capacity (Engle, 2002).

**Inhibition**

Inhibition occurs when one withholds prepotent behavioral and cognitive responses, for example, when children are first asked to respond to different colors and then to stop responding when a sound beeps. Previous longitudinal (Kochanska, Murray, & Harlan, 2000) and cross-sectional (Carlson, 2005) studies have been done on the development of inhibition. One major question in studying inhibition has been the extent to which working memory is involved in carrying out inhibitory behaviors. Some inhibition measures have a strong working memory component and require children to learn and keep rule information in mind (e.g., “Simon Says” type of tasks); when working memory demands are high (for a given task and a given developmental level), efforts to inhibit a prepotent response are more likely to fail (Roberts & Pennington, 1996). Other measurements of inhibition have lower working memory demands (Carlson, 2005) and sometimes involve motivation and emotion (e.g., delay of gratification tasks). In addition to separating the effect of working memory on inhibition measures, many other studies have focused on associating inhibition with working memory. Participants with strong working memory were found to perform better than those with weak working memory on inhibition tasks in general (Engle, 2002). Notably, individuals with high working memory capacity have performed substantially better on antisaccade tasks that required them to inhibit their proponent response of looking at a distractor (Kane, Bleckley, Conway, & Engle, 2001).

**Attentional control**

Despite the importance of working memory, some models have suggested that attentional control, or the ability to ignore irrelevant information and focus on tasks, is an important component of EF for successful goal-oriented behaviors (e.g., Iguchi, Hoshi, Tanosaki, Taira, & Hashimoto, 2005). Engle, Kane, and Tuholski (1999) argued that working memory can be called “controlled attention” because it reflects the ability to activate memory representations and either bring them into focus or keep them in focus, particularly when interfered with or distracted. Indeed, performance on attentional control tasks has been found to differentiate preschoolers with low and high working memory span (Espy & Bull, 2005). Because attentional control is likely to be required for all goal-oriented behaviors, we expect it to be generally associated with other components of EF and academic achievement in general.

In sum, differences between components of EF exist, but their relations during early childhood are complicated and poorly understood and little is known about cultural variation in these relations. Notably, previous studies comparing Chinese and American children have focused primarily on inhibition tasks as their sole EF measure. For example, Sabbagh et al. (2006) primarily used EF tasks that mainly measure response inhibition (e.g., Day/Night Stroop, Grass/Snow Stroop, Bear and Dragon task), cognitive flexibility, and impulsivity but did not use those that mainly measure attentional control or working memory.

Cultural differences in EF and academic achievement found so far could be due to several factors, including the predominance of inhibition tasks in the sparse cross-cultural research done to date. An additional source of cultural variation could be due to socialization and differences in specific cultural practices that take place in educational settings. For example, Asian children appear to receive intensive practice in inhibiting behaviors and controlling their attention in normal classroom practice.
Lan et al. (2009) reported that Chinese first-grade teachers gave substantially more proactive self-regulatory instructions, such as “do something properly” and “avoid doing something,” compared with American teachers, who often gave reactive instructions after students’ misbehaviors. Chinese teachers’ proactive instructions also included the directive “pay attention.” Such training may allow Chinese students to outperform their American counterparts on some aspects of EF such as inhibition. Alternatively, it could also be the case that Chinese children perform similarly on all aspects of EF compared with American children. It is possible that the executive system is relatively culture free; thus, children in a diversity of societies could develop EF at similar speeds. Rather than rule out any of these explanatory possibilities explicitly, our objective was to contribute to the growing body of work addressing the cross-cultural relations between EF components and achievement.

**EF as a key predictor of achievement**

Our second objective was to investigate the links between components of EF and three aspects of academic achievement: simple math, complex math, and reading achievement. We distinguished between simple math (defined as counting) and complex math (defined as calculation), anticipating that these are likely to be associated with different components of EF. Preschoolers and kindergarteners with stronger EF achieve higher levels of literacy, vocabulary, and mathematics compared with children with lower EF (McClelland et al., 2007). In another study, Bull and Scerif (2001) found that students with better EF skills (including inhibition, working memory, and task switching) had stronger math abilities compared with students with weak EF skills. The components of EF also predict achievement. Strong working memory skills have been consistently associated with higher academic achievement (Adams, Bourke, & Willis, 1999; Gathercole & Pickering, 2000). After controlling for general intelligence and attentional control, inhibition was found to uniquely predict math achievement and literacy in kindergarten (Blair & Razza, 2007; Espey et al., 2004). Dobbs, Doctoroff, Fisher, and Arnold (2006) found that children with attentional control difficulties had weaker math skills than their peers with fewer attentional control difficulties. Although these studies have shown the importance of separate components of EF to academic outcomes, few studies have included a battery of inhibition, working memory, and attentional control tasks and studied their unique contributions to various aspects of academic achievement. In addition, research linking components of EF and achievement has been conducted primarily in the United States, so relatively little is known about cultural variation in the development of EF skills. In the current study, we analyzed data collected in the United States and China separately and compared the pattern of relations within each country and across the two countries.

Another objective of this study was to address how these components differentially predict academic skills with variable demands on EF. These include simple math (counting), complicated math (calculation), and reading. According to Geary and Bjorklund (2000), human abilities can be differentiated into primary and secondary abilities. Primary abilities refer to abilities that have a long evolutionary history and are required for survival and adaptation needs such as language and counting small numbers (e.g., counting from 1 to 4). Secondary abilities refer to those culturally necessary and determined abilities that require focused practice to acquire competence such as reading and mathematics. EF is proposed to be vital for acquiring secondary abilities because they require sustained attention and persistence. This hypothesis suggests that the more sophisticated and complex the secondary skill set, the more important EF will be for its acquisition. We used two math tests that we expected would vary in their EF demands. Separating simpler math (e.g., counting) and more complicated processes (e.g., calculation) would allow us to specify the role of EF components in these two skills. We anticipated that working memory would be particularly important for predicting complex math abilities such as calculation, whereas all components of EF would be equally important for counting; that is, no component would be particularly important for counting, but because younger children would still be refining counting skills, they would rely on all EF components even though counting is simpler. In addition, although reading is regarded as a secondary ability, it is unclear whether reading is associated with EF as much as is mathematics. Indeed, some studies have suggested that EF is more strongly associated with mathematics than with reading English (Blair & Razza, 2007; Ponitz et al., 2009). The current study differentiates among simple math, complex math, and
reading in addition to investigating the relations of each of the EF components to these academic skills.

**The current study**

Taken together, three aspects of EF have been consistently associated with early math and reading abilities. However, research considering all three components (i.e., inhibition, working memory, and attentional control) and investigating their unique contributions to reading and math achievement is limited, especially in a cross-cultural context. We asked the following research questions:

1. Is there cross-cultural variation in children’s performance on a battery of EF tasks that include inhibition, working memory, and attentional control measures?

2. Are the relations between EF components and academic achievement similar across the two cultures?

Based on previous findings, we predicted that inhibition and working memory would jointly predict all academic outcomes, particularly math ability. However, because inhibition measures may rely on working memory for remembering rule information (Pickering & Gathercole, 2004), inhibition alone might not uniquely predict math achievement. We anticipated that these associations would be found in both cultures because of the strong neurological and evolutionary basis for developing EF skills.

**Methods**

**Participants**

**China**

Teachers and children were recruited from two urban public schools in Beijing. The final sample consisted of 119 preschool-age children (46 4-year-olds and 73 5-year-olds). Their average age was 5.02 years \( (SD = 0.62) \), ranging from 3.12 to 6.00 years (50% female), at the time of testing. All participants were Mandarin-speaking monolingual children of Chinese origin.

**United States**

Teachers and children were recruited from two preschools in a rural and suburban county in the Midwest. The final sample consisted of 139 children from two schools (two non-native English speakers were excluded from the final results due to their failure to complete the tasks). The majority of U.S. participants (69.2%) were Caucasian, and the rest were Chaldean (people of the Chaldean Christians, comprising the majority of Catholic people in Iraq, 10.8%), Asian Americans (9.2%), African Americans (6.2%), or Latino/a (4.6%). Preschoolers were on average 4.90 years old \( (SD = 0.54) \), ranging from 3.4 to 5.5 years, and the sample was 43% female.

**Procedure**

Children in both countries were administered a battery of EF measures and two assessments of academic achievement: mathematics and reading. Research assistants from local universities (i.e., graduate students from the Chinese Academy of Sciences–Institute of Psychology in China and undergraduate students from the University of Michigan in the United States) were trained to administer all tasks. They participated in two group training sessions and practiced giving the battery of tasks five times to each other as well as to persons unfamiliar with the study. They were observed by the first author before being certified to administer tasks.

Tasks were administered to individual children in quiet rooms located at the children’s schools. The battery of tasks was split into two sessions lasting 15–30 min. Chinese children attended preschools for approximately 7 h each day; therefore, two sessions were administered on the same day: one in...
the morning and one in the afternoon after lunch and nap time. American children attended preschool for a half day either in the morning or in the afternoon; therefore, only one testing session was administered on any given day. All children were given stickers, pencils, or erasers as they went through the assessment battery. The order of the tasks was counterbalanced.

**Measures**

Three EF tasks and two achievement tasks were selected based on evidence for their reliability and appropriateness for use with young children. In the United States, all tasks were given in English. In China, all tasks were given in Mandarin Chinese. We used the same EF measures at both sites but with different achievement measures; the U.S. achievement measures included culture-specific items that would not have been appropriate in China (e.g., calculations using U.S. currency). English versions of the EF tasks were translated and back-translated by two bilingual Chinese–English speakers for use in China.

**EF battery**

**Inhibition.** To measure inhibition, the Head–Toes–Knees–Shoulders (HTKS) task (Ponitz et al., 2008) was used (Diamond, 2002). Children were asked to play a game in which they were instructed to do the opposite of what the experimenter told them to do. When asked to touch their head (or toes), children were directed to do the opposite and instead touch their toes (or head). After four practice commands, children were given 10 consistent, randomly ordered commands to touch their head or toes. Then children were told to use their knees and shoulders and do the opposite of what the experimenter told them to do. After four additional practice items, children were given 10 more commands with one of four directives (i.e., to touch their head, toes, knees, or shoulders). Correct responses on all items received a score of 2, self-corrects (i.e., discernible motion to incorrect response, with final response given correct) received a score of 1, and incorrect responses received a score of 0. The maximum possible score was 40.

**Working memory.** To measure working memory, the Sentence Completion task (adapted from the reading span task developed by Towse, Hitch, and Hutton (2002)) was used. Children were instructed to listen to a set of short sentences from the experimenter. Each sentence was missing its final word (e.g., “Twinkle, twinkle, little ____”). Children were asked to complete the sentence. After completing a set of sentences, they were required to recall the final word in each sentence in the set. Children started with one sentence set and stopped when they failed to repeat any final words in a given set. The maximum number of sentences in a given set was four, and each of the final words (recalled in any order) was worth 1 point. There were five sentences in each set. Final composite scores were computed based on the total number of final words children recalled independent of order. The total maximum possible score was the same in both countries (i.e., 50 points). Most sentences used by Towse et al. (2002) were included, but because the current study was based in the United States rather than the United Kingdom, we excluded some sentences and generated new ones for use in the United States and China. The Chinese version of the Sentence Completion task was translated based on the English version. Translations were carefully chosen to make the length of the sentences, key words, and number of ideas comparable across cultures. For example, “the color of a banana is ____” was translated as “香蕉的颜色是 ____”; all had six words/characters and the same number of key words/ideas. Note that not all sentences could be translated into equivalent forms; in the cases where such translations did not apply, other words were chosen to ensure that the length of key words and number of ideas were comparable across cultures. The translated task was evaluated by a group of developmental psychologists from the Chinese Academy of Sciences–Institute of Psychology and the University of Michigan and was piloted in a preschool in China before being finalized for the current study.

**Attentional control.** The Woodcock–Johnson Pair Cancellation task from the Woodcock–Johnson III Tests of Cognitive Abilities was used to measure attentional control (Woodcock, McGrew, & Mather, 2001). Children were presented with a piece of paper covered with randomly sequenced images of
dogs, balls, and cups. They were asked to circle as many ball–dog pairs with the dog after the ball as they could in 3 min. The maximum possible score was 69.

**Achievement battery**

**United States.** In the United States, two subtests of achievement from the Woodcock–Johnson Psychological–Educational Battery-III Tests of Achievement were used (Woodcock & Mather, 2000): applied problems (mathematics) and letter–word identification (reading). Applied problems assessed early numeracy skills and included questions about quantity, time, money, and word problems. Items were distinguished by skills required, and two subscores were calculated for counting (including items that involve counting numbers of objects) and calculation (including items that involve adding or subtracting numbers of objects). Three nonrelated items (e.g., “what does the clock say?”) were excluded from the analysis. The interitem reliability (Cronbach’s alpha) was .72 for the counting subset, and it was .79 for the calculation subset. Letter–word identification measured early literacy, requiring children to name letters and read actual words. On both subtests, items increased in difficulty, and testing stopped after children answered six items incorrectly. *W* scores were used for all analyses.

**China.** The ZAREKI–KP task (Investigation of Number Processing and Calculation in Children Attending Preschool) (Von Aster, 2001) was designed for preschoolers and has shown reliability and predictive validity. To measure math abilities, the subtests of counting and calculation (i.e., addition and subtraction) were used in the current study. The experimenter administered the testing items verbally and recorded the results on paper. Examples of counting items included “start from one and count as far as you can get” and “I’ll say a number and you tell me the number before it.” Examples of calculation included “what’s one plus one” and filling in blanks before or after the “±” sign. Liu (2007) translated the task into Mandarin, administered it to 184 preschoolers in Beijing, and followed them into their first year of elementary school. Liu reported reliability values for counting and calculation subsets as .84 and .87, respectively. Performance was also significantly correlated with teacher report and cognitive tasks in elementary school. To measure reading, a 61-item character recognition task was used (Chow, McBride-Chang, Cheung, & Chow, 2008). All of the traditional Chinese characters (i.e., characters that are either in the same forms as or in more complicated forms of the simplified characters, mainly used in Taiwan and Hong Kong) were translated into corresponding simplified Chinese characters (used mainly in Mainland China). The characters were arranged in order of increasing difficulty, and children were required to read each character aloud. Testing stopped when children failed to read 15 consecutive items. The maximum score for the combined task was 61.

**Results**

**Analytic plan**

Because the missing data rate was very low in both China and the United States (see Table 1 for the final number of participants for each task), listwise deletion was used. Preliminary analysis revealed no significant sex or age difference across cultures (*t*s < 1.96, *ns*).

To investigate cultural differences in performance and associations among components of EF, we examined the nature and variability of scores on each EF task and compared the performance of children from the two countries on the EF battery. We also examined zero-order correlations among components of EF within each country. To address Research Question 2 about the links between EF and achievement, we examined the unique and joint predictability of the individual EF components to the academic achievement measures within each country.

**Research Question 1: What is the nature and variability of the tasks and the relative performance of Chinese and American children?**

Table 1 displays descriptive statistics for all of the measures. In comparison with Chinese children, American children scored significantly lower on inhibition, *t*(241) = 10.2, *p* < .001, *d* = 1.29, and
attentional control, $t(254) = 6.9$, $p < .001$, $d = 0.83$. However, working memory performance was comparable across groups, $t(250) = 1.5$, ns. The results still hold when controlling for age.

We also calculated zero-order correlations between EF components in each country while controlling for age. Table 2 shows that most components of EF significantly correlated with each other in both countries except attentional control and inhibition in the United States. A comparison among these significant correlations both within and between cultures yielded nonsignificant differences.

**Research Question 2: How do components of EF predict reading and math achievement jointly and uniquely in each country?**

First, correlation analysis again showed generally significant correlations of moderate magnitude between components of EF and aspects of achievement. The correlations between reading and working memory were comparable to those between counting and working memory and between calculation and working memory in China ($z < 1.9$, ns) but were significantly lower than those between counting and working memory and between calculation and working memory ($z > 1.96$, $p < .05$) in the United States.

Next, the unique and joint contribution of components of EF to reading and mathematics (including counting and calculation) were investigated in separate models for each country. All of the predictors

### Table 1

Descriptive statistics for EF and achievement measures in two countries.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>M (SD)</th>
<th>Range</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (years)</strong></td>
<td></td>
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</tr>
<tr>
<td>China</td>
<td>118</td>
<td>5.02 (0.62)</td>
<td>3.1–6.0</td>
<td>−0.46</td>
<td>−0.54</td>
</tr>
<tr>
<td>United States</td>
<td>125</td>
<td>4.90 (0.56)</td>
<td>3.4–5.5</td>
<td>−0.09</td>
<td>0.42</td>
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<tr>
<td><strong>HTKS</strong></td>
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<tr>
<td>China</td>
<td>118</td>
<td>31.8 (8.8)</td>
<td>0–40</td>
<td>−2.10</td>
<td>4.60</td>
</tr>
<tr>
<td>United States</td>
<td>125</td>
<td>17.8 (12.5)</td>
<td>0–37</td>
<td>−0.23</td>
<td>−1.34</td>
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<tr>
<td><strong>Sentence Completion</strong></td>
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<tr>
<td>China</td>
<td>118</td>
<td>6.8 (3.7)</td>
<td>0–16</td>
<td>0.08</td>
<td>−1.20</td>
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<tr>
<td>United States</td>
<td>134</td>
<td>6.2 (2.5)</td>
<td>0–11</td>
<td>−0.60</td>
<td>0.50</td>
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<tr>
<td><strong>WJ–Pair Cancellation</strong></td>
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<tr>
<td>China</td>
<td>118</td>
<td>20.0 (8.0)</td>
<td>0–40</td>
<td>−0.32</td>
<td>0.32</td>
</tr>
<tr>
<td>United States</td>
<td>138</td>
<td>13.4 (8.0)</td>
<td>1–20</td>
<td>0.30</td>
<td>−0.07</td>
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<td><strong>Reading</strong></td>
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<tr>
<td>China</td>
<td>117</td>
<td>23.2 (20.0)</td>
<td>0–61</td>
<td>0.55</td>
<td>−1.10</td>
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<td>United States</td>
<td>133</td>
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<td>1–26</td>
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<tr>
<td>China</td>
<td>117</td>
<td>2.4 (0.84)</td>
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<td>117</td>
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<td>0–6</td>
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<td>9.3 (2.2)</td>
<td>1–11</td>
<td>−2.00</td>
<td>3.70</td>
</tr>
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**Note.** HTKS, Head–Toes–Knees–Shoulders task; WJ, Woodcock-Johnson.

### Table 2

Correlations among independent and dependent variables.

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<tr>
<th></th>
<th>Sentence Completion</th>
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<th>Counting</th>
<th>Calculation</th>
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<td>China</td>
<td>.38**</td>
<td>.23**</td>
<td>.19**</td>
<td>.47**</td>
<td>.22**</td>
</tr>
<tr>
<td>United States</td>
<td>.25</td>
<td>.08</td>
<td>.20**</td>
<td>.22**</td>
<td>.29**</td>
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<td><strong>Sentence Completion</strong></td>
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<td>China</td>
<td>.31**</td>
<td>.33**</td>
<td>.38**</td>
<td>.44**</td>
<td></td>
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<tr>
<td>United States</td>
<td>.32</td>
<td>.07</td>
<td>.31**</td>
<td>.24**</td>
<td></td>
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<tr>
<td><strong>WJ–Pair Cancellation</strong></td>
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<tr>
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<td>.48**</td>
<td>.30**</td>
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<tr>
<td>United States</td>
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<td>.42**</td>
<td>.24**</td>
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<td>.40**</td>
<td>.37**</td>
<td></td>
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</tr>
<tr>
<td>United States</td>
<td>.44**</td>
<td>.37**</td>
<td>.30**</td>
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<tr>
<td><strong>Counting</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>.35**</td>
<td></td>
<td>.35**</td>
<td></td>
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<tr>
<td>United States</td>
<td>.34</td>
<td></td>
<td>.43**</td>
<td></td>
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</table>

**Note.** HTKS, Head–Toes–Knees–Shoulders task; WJ, Woodcock-Johnson.

* $p < .01$.

** $p < .001$. 
were entered simultaneously into a regression model using type III sums of squares. The beta of each predictor represented its contribution to the outcome variable while controlling for all of the other variables (see Table 3 for regression coefficients).

**China.** In China, inhibition uniquely predicted counting ($\beta = .31, t = 4.8, p < .001$) but not calculation ($\beta = .04, t = 0.4, ns$) or reading ($\beta = .05, t = 0.5, ns$). Working memory uniquely predicted all aspects of achievement; with each additional working memory score, reading score increased .22 ($\beta = .22, t = 2.3, p < .05$) and calculation score increased .35 ($\beta = .35, t = 3.9, p < .001$), but counting score increased only .13 ($\beta = .13, t = 1.7, p < .10$). Attentional control uniquely predicted all aspects of achievement as well (reading: $\beta = .27, t = 2.9, p < .01$; calculation: $\beta = .18, t = 2.0, p < .05$; counting: $\beta = .36, t = 4.5, p < .01$).

We were also interested in the extent to which overlapping variance in inhibition and working memory contributed to academic outcomes. In a follow-up analysis, we compared two incremental models for each achievement measure (Tables 3 and 4 for regression coefficients): models with inhibition but not working memory as a predictor and models with both inhibition and working memory measures. This analysis allowed us to examine the extent to which standardized regression coefficients changed across models with the addition of working memory. In general, the beta coefficients for inhibition decreased when working memory was included. This was particularly evident for reading and calculation as opposed to counting. For example, the standardized beta of inhibition decreased from .12 to .05 when working memory was added to the model for reading. Similarly, inhibition tended to predict calculation ($\beta = .15$) when controlling for age and the attention variables, but when working memory variables were added into the model, it no longer did so ($\beta = .04$). In contrast, inhibition significantly predicted counting scores with working memory ($\beta = .31$) and without working memory ($\beta = .35$) in the model.

**United States.** In the United States, results showed somewhat consistent patterns as in China for mathematics but not for reading. Although inhibition uniquely predicted counting ($\beta = .26, t = 2.5, p < .001$) and calculation ($\beta = .19, t = 1.9, p < .10$), it did not do so for reading ($\beta = .17, t = 1.5, ns$). Likewise, working memory was also a unique predictor of counting ($\beta = .21, t = 2.0, p < .05$) and calculation ($\beta = .20, t = 2.6, p < .05$) but not of reading ($\beta = -.10, t = -0.6, ns$). Although only marginally significant, attentional control tended to uniquely predict reading ($\beta = .12, t = 1.7, p < .10$) and calculation ($\beta = .21, t = 1.7, p < .10$) but not counting ($\beta = .20, t = -0.4, ns$). Finally, inhibition predicted counting regardless of whether controlling for working memory ($\beta = .26, t = -2.5, p < .05$) or not ($\beta = .36, t = -3.9, p < .001$). However, it predicted calculation only when not controlling for working memory ($\beta = .26, t = 2.6, p < .05$). By adding working memory to the model, inhibition became a marginally significant predictor of calculation ($\beta = .19, t = 1.9, p < .10$).

**Discussion**

Consistent with prior work, Chinese preschoolers significantly outperformed their American counterparts in inhibition and attentional control tasks, with large effect sizes. However, there was no difference in working memory performance between the two countries. The relations between EF components were also similar across cultures, with strong and positive correlations. Finally, the associations between components of EF and aspects of achievement were largely similar across cultures. Working memory appears to be the most salient predictor of most aspects of achievement, especially for complex tasks. Inhibition uniquely predicted performance on math achievement tasks that involved relatively simpler processes in both countries, and attentional control predicted all aspects of achievement in both countries. Notably, the core difference was in how working memory related to reading cross-culturally; in China, working memory was as important for predicting reading as for predicting mathematics, whereas in the United States, working memory was more strongly related to counting and calculation than to reading. We highlight two themes in our discussion: cultural differences in direct comparison of EF components and relations between components of EF and academic achievement.
Table 3
Models with and without working memory predictors: China.

<table>
<thead>
<tr>
<th></th>
<th>Model with working memory predictors (Reading)</th>
<th>Model without working memory predictors (Reading)</th>
<th>Model with working memory predictors (Counting)</th>
<th>Model without working memory predictors (Counting)</th>
<th>Model with working memory predictors (Calculation)</th>
<th>Model without working memory predictors (Calculation)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>SE</td>
<td>β</td>
<td>t</td>
<td>B</td>
<td>SE</td>
</tr>
<tr>
<td>Age</td>
<td>2.8</td>
<td>3.0</td>
<td>.87</td>
<td>.09</td>
<td>3.0</td>
<td>3.1</td>
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<td>.05</td>
<td>.53</td>
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<td>.22</td>
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<td>WJ–Pair Cancellation</td>
<td>.70</td>
<td>.25</td>
<td>.27</td>
<td>2.90</td>
<td>.85</td>
<td>.24</td>
</tr>
<tr>
<td>Sentence Completion</td>
<td>1.2</td>
<td>.52</td>
<td>.22</td>
<td>2.30</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>


* p < .10.
` p < .05.
** p < .01.
*** p < .001.
Table 4
Models with and without working memory predictors controlling age: United States.

<table>
<thead>
<tr>
<th></th>
<th>Model with working memory predictors</th>
<th>Model without working memory predictors</th>
<th>Model with working memory predictors</th>
<th>Model without working memory predictors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Reading)</td>
<td>(Reading)</td>
<td>(Counting)</td>
<td>(Counting)</td>
</tr>
<tr>
<td></td>
<td>B         SE   β    t</td>
<td></td>
<td>B         SE   β    t</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>.12       .10  .15  1.10</td>
<td>.04        .09  .05  0.44</td>
<td>.10        .04  .32  1.30</td>
<td>.09        .04  .23  2.20'</td>
</tr>
<tr>
<td>HTKS</td>
<td>.06       .04  .17  1.50</td>
<td>.07        .04  .09  0.05</td>
<td>.04        .01  .26  2.50'</td>
<td>.06        .01  .36  3.90'***</td>
</tr>
<tr>
<td>WJ–Pair Cancellation</td>
<td>.12      .07  .21  1.70'</td>
<td>.16        .07  .27  2.40'</td>
<td>.00        .03  .05  0.40</td>
<td>.04        .03  .13  1.30</td>
</tr>
<tr>
<td>Sentence Completion</td>
<td>-.12    .21  -.10  -.60</td>
<td>.-4        .07  .21  2.00'</td>
<td>.-4        .03  .13  1.30</td>
<td>.29        .11  .28  2.60'</td>
</tr>
</tbody>
</table>


* p < .10.
* * p < .05.
* * * p < .001.
Cultural similarities and differences in EF components

Our results are consistent with previously reported cultural differences in inhibition and attentional control, indicating the advantage that Asian children have on these tasks relative to North American children. Importantly, we have extended prior work by including an attentional control task and a working memory task (Sabbagh et al., 2006), showing that Asian children did not outperform American children uniformly on all aspects of EF. Namely, their advantage was demonstrated in inhibition and attentional control measures but not in working memory. This pattern of findings may arise because of the cultural emphasis on self-control during the primary school years in Asian countries. Observational studies of classrooms indicate intensive training on skills such as following directions and concentrating on subject matter (Lan et al., 2009) in Chinese classrooms. Kwon (2004) also reported that Korean teachers enforce discipline in Korean nurseries and kindergartens. In contrast, in American classrooms, teachers often value free choice and self-expression (Chen et al., 1998). Although teacher and parent behaviors may emphasize impulse control differently across cultures, it is more difficult (at least conceptually) to find variations in children's experiences across cultures that would produce differences in working memory. Notably, the translated sentences used in the Sentence Completion working memory task were shorter in Chinese than in English because the Chinese language generally requires fewer words to express the same meaning as in English. Therefore, despite a possible advantage because they heard shorter sentences, Chinese children's performance was on par with that of the American children. Thus, results did not support the hypothesis that Chinese children outperform American peers in all aspects of EF. Specifying the origin of their advantage on inhibition and attentional control tasks (e.g., environment or genetic differences) is an important direction for future research. In addition, it remains to be determined whether there are cultural differences in some aspects of working memory that were not measured here, for example, spatial (vs. verbal) working memory.

Despite cultural differences in performance on inhibition and attentional control, we found that the correlations between the individual EF components were similar, with significant and positive correlations of moderate magnitude in both countries. This may imply that despite the mean differences on individual EF tasks across cultures, the associations are culturally comparable. The strength of relations between components of EF may tend to be consistent across distinct cultures in part because of the strong neurological basis for developing EF skills (Friedman et al., 2008) and the likely survival advantage conferred to humans with strong EF as the species evolved. In other words, before culturally specific skills such as reading and mathematics became an important part of human functioning, the coordination of subcomponents of EF (i.e., inhibition, working memory, and attentional control) had an adaptive cognitive function. In addition, although humans tend to highlight cultural differences, the experiences and genetic factors that determine the strength of EF component associations may be more similar than different across cultures.

EF and math achievement

We now discuss whether components of EF related to achievement similarly in the two countries, beginning with mathematics. We distinguished between simple math (counting) and complex math (calculation) based on the rationale that these may vary in their cognitive processing demands. For example, counting relies on recalling previous knowledge about numbers and inhibiting previous numbers in the sequence so as to produce the next number. In contrast, calculating requires the ability to implement multiple processes at the same time such as recalling the rules of adding or subtracting, remembering the numbers that need to be added or subtracted, and performing these two steps sequentially. Thus, calculating requires both inhibition and working memory, but only one of these may be important for producing the correct answer. Indeed, our results indicated that working memory uniquely predicted calculation in both cultures, whereas inhibition uniquely predicted only counting.

One reason why inhibition did not uniquely predict calculation could be that inhibition relies heavily on working memory during early childhood; children must learn and keep rules in mind, and if children cannot remember the rules while doing the task, they will continue to inflexibly choose
the incorrect response (Diamond, 1998). Indeed, previous research has indicated the importance of working memory in relation to inhibition in predicting math achievement. For example, in a study examining math ability in first graders, independent effects were reported for inhibition, attention shifting, and working memory aspects of EF, with the most robust relation being that for working memory (Bull & Scerif, 2001). In the current study, we were able to extend this work by differentiating between counting and calculation, thereby demonstrating the importance of working memory for calculation.

Some researchers have also made distinctions between simple inhibition tasks (i.e., tasks that involve minimum working memory such as delay of gratification) and more complex inhibition tasks (i.e., tasks that require children to learn rule information first and then inhibit according to rules such as stop signal tasks) (Carlson & Moses, 2001; Diamond, 2001, 2002; Garon et al., 2008). Notably, our measure is a more complex than previous measures in which inhibition essentially depends on working memory to successfully inhibit prepotent responses (e.g., children touching their toes instead of their head). Using a different measure of inhibition and not separating simple and complex math may lead to different results. For example, Espy et al. (2004) found inhibition to uniquely predict emergent math skills.

Given the importance of working memory for math achievement and the lack of cultural practices that explicitly target working memory, future studies might focus on identifying factors associated with individual differences in working memory and design possible interventions for working memory training. Quasi-experimental work using a cutoff design suggests that schooling, specifically the years of prekindergarten and kindergarten, improves working memory for children who attend school compared with same-age peers who, because of arbitrary school cutoff dates, do not attend at the same time (Burrage et al., 2008).

**EF and reading achievement**

There were also interesting patterns in our analyses of the contribution of EF components to reading achievement. Working memory was a unique predictor for reading Chinese but not for reading English. Attentional control predicted reading Chinese very strongly and was a marginally significant predictor for reading English, whereas inhibition did not predict reading in either country. These findings suggest that reading places higher working memory demands on Chinese readers than on English readers, and this can likely be attributed to differences between reading a logographic-based orthographic system and reading an alphabet-based one. A character (i.e., basic writing unit) can be spatially analyzed into a hierarchical structure involving several different-sized units, conventionally including the radical layer, the logo grapheme layer, and the strokes (State Language Commission, 1998). Strokes are combined in rich spatial relations to form characters. Many characters are visually quite similar; for example, two nearly identical characters, “＋” (earth, tu3) and “＋” (soldier, shi4), have completely different meanings and pronunciations. To identify a character, one must identify not only each stroke but also its form and position in relation to the other strokes. In the current example, “＋” has a longer lower vertical stroke, whereas “＋” has a longer upper stroke. Therefore, Chinese readers must differentiate among many similar characters, and this requires one aspect of attentional control, interference resolution or the ability to ignore irrelevant information (Hamilton & Martin, 2005), in addition to actively comparing them in working memory.

There is some prior evidence that the process of identifying Chinese characters may at least partially require working memory and attentional control (e.g., differentiating aspects of characters from the distracting parts of the characters). Huang and Hanley (1994) found that performance on a visual discrimination task (a process that requires matching a target figure with three other rotated or displaced figures, differentiating figures, and comparing them in working memory) was significantly related to the reading ability among Hong Kong and Taiwanese schoolchildren; no such correlation was found between reading ability and visual skills among British schoolchildren. Thus, Chinese readers may need to use attentional control to differentiate characters and process them in their working memory when reading. In comparison, although the English language may require one to sound out all letters in a word to map them onto an existing phonological representation of the word, the letter–word identification task used in the United States may primarily require identifying unique letters.
and simple words that are easily distinguished by sight and, thus, rely less heavily on working memory and attentional control. It is possible that a decoding task such as the Woodcock–Johnson III Word Attack subtest in English, where children must remember and then blend together letter sounds to read pseudowords, might place greater demands on working memory compared with letter–word identification.

Implications and limitations

Our work confirmed previous findings that Chinese preschoolers have superior inhibition and attentional control performance compared with U.S. children, and this might be associated with deliberate cultural training at home and at school (Miller, Kelly, & Zhou, 2005) but comparable working memory performance. Higher EF is associated with higher academic achievement in general. Notably, working memory is important for children in both countries to perform better on complex math tasks and for children in China to perform better on reading, and attentional control may be particularly helpful for reading Chinese in addition to learning mathematics. These intriguing results call for studies on the development of EF, particularly training each component of EF in both China and the United States.

We mention three limitations of the study. First, due to the large number of total tasks used and data points collected, only one task was included to measure each component of EF. Although all of these tasks are commonly used and were reliable in our study, selecting a variety of measures in future studies could provide a more comprehensive picture of EF and academic achievement. Second, the two samples included in the study represented two local areas within two large and diverse countries (i.e., a metropolitan city in China and a midwestern city in the United States). Although we have no reason to attribute cultural differences on inhibition and attentional control to sampling differences and possible differences between urban and rural areas, a more comprehensive sampling strategy and a longitudinal study would yield more reliable results. Third, due to the difference in language and limited availability of culturally appropriate achievement tasks, we used different achievement measures in United States and China. If possible, future studies should use the same achievement tasks.

Conclusion

The current study has demonstrated that although Chinese children outperformed American children on inhibition and attentional control tasks, they did not have advantages in working memory. Despite these differences, the relations between components of EF were similar across cultures; all components of EF were related to each other. Furthermore, the links between EF and mathematics were also similar in China and the United States. Attentional control was generally important for all aspects of achievement and working memory for complex math skills. This study highlights the importance of EF for early school achievement, particularly more complex aspects of achievement such as calculation tasks. In sum, the data provide insight into both cultural variability and consistency in the development of EF during early childhood.

Acknowledgments

This study was supported by a China Seed Grant from the University of Michigan and the Chinese Academy of Sciences–Institute of Psychology.

References


