A Meta-analysis of Executive Functioning in Chinese and North American Children with Attention Deficit/Hyperactivity Disorder

by

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Abstract

This study synthesizes findings from North American and Chinese studies that compare the performance of children with and without Attention Deficit Hyperactivity Disorder (ADHD) on executive function tasks. The relationship between the executive functions and ADHD in Chinese and North American children are found to be best described by multimodal model. The magnitude of average performance differences between Chinese and North American children with and without ADHD on each executive function domain fell into medium range. Patterns of effect sizes were statistically the same on response inhibition, working memory planning and vigilance; however, heterogeneity in the variance of effects is statistically detectible in Chinese studies. This analysis indicated that the variability of effects of EFs might be partially explained by age and IQ; however, the culture variance and validity of neuropsychological tests for executive functions adopted across different languages and cultures should be discussed in the future study.

Keywords: Meta-analysis; Attention Deficit/Hyperactivity Disorder; executive functioning deficits; Chinese; North American

To my father, mother, grandparents and
my dear friend Xiao Meng.

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List of Acronyms

ADHD	Attention Deficit Hyperactivity Disorder
CD	Conduct Disorder
C-WISC	Chinese version of third edition Wechsler Intelligence Scale for Children
DBD	Disruptive Behaviour Disorder
DSM	Diagnostic and statistical manual of Mental Disorders
EF	Executive Function
FIQ	Full Scale IQ
LD	Learning Disability
ODD	Oppositional Defiant Disorder
RD	Reading Disability
SCWT	Stroop Colour Word Test
WISC	Wechsler Intelligence Scale for Children
WM	Working memory

1. Introduction

1.1. Overview

Findings from a number of studies suggest that children diagnosed with Attention Deficit Hyperactivity Disorder (ADHD; DSM-V, 2013) have limitations in executive functions, a suite of cognitive resources that support self-regulation and the efficiency of goal-directed behavior (Barkley, 1997, 1999, 2001, 2006; Miyake et al., 2000; Pennington & Ozonoff, 1996). Relative to same age peers without ADHD, children with ADHD often have difficulty performing on executive function tasks that require updating and monitoring of information in working memory (Barkley, 1997,1999, 2001, 2006; Liu & Wang, 2002; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Yao & Li, 2003; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005a), cognitive flexibility (e.g., set shifting; Lawrence et al., 2004; Miyake et al., 2000; Yao & Li, 2003), and/or response inhibition(Barkley, 1997; Berlin, Bohlin, Nyberg, & Janols, 2004; Miyake & Friedman, 2012; Schoemaker et al., 2012; Wodka et al., 2007).

In children with ADHD, these weaknesses in executive functions have been linked to inefficient planning and organization, and inadequate problem-solving strategies in social contexts (Barkley, 2001; Anderson, Levin, &Jacobs, 2002). More recently, findings from longitudinal research also suggest that variation in developmental trajectories of executive functions is associated with differences in the severity of symptoms among school-aged girls with ADHD (Miller, Loya, & Hinshaw, 2013). The studies cited above were conducted on samples of children living in the United States (US), and findings were reported in US academic journals. However, ADHD is a disorder that is diagnosed in countries and cultures throughout the globe (Farone, Sergeant, Gillberg, & Biederman, 2003; Hinshaw et al., 2011; Liu & Wang, 2002; Li, Zou, Jing, Tang, & Chen, 2005; Willcutt, 2012), and more information is needed to determine whether the association between executive functions and ADHD observed in US samples is found across cultures. The aim of the present research is to compare findings from studies that examine executive function-ADHD relations in Chinese children living in Asia with findings from research on the same topic conducted with children living in North America.

Comparisons between Chinese and US research findings on this issue are timely. In China, estimates of the prevalence rate of ADHD in the general population range widely depending upon the region surveyed and diagnostic criteria (Chen et al., 2004; Hinshaw et al., 2011; Hu & Yu, 1999; Zhang, Liu, Gu, Liao, & Ran, 2007); however, recent estimates suggest that on average, ADHD is found in approximately 7% of the population (Chen et al., 2004; Zhang et al., 2007; Zhang & Yu, 2000). In the US, prevalence rates also vary regionally; however, 9.5% of children aged 4-17 years (5.4 million) have been diagnosed with ADHD as of 2007 (Visser, Bitsko, Danielson, Perou, & Blumberg, 2010). In both China and the US, males are more likely than females to be diagnosed with ADHD —13.2% males vs. 5.6% females in U.S., (Visser et al., 2010) and 6% males vs. 3% females in China (Zhang et al., 2007), which suggests that there is some overlap, at least with respect to gender, in how ADHD is perceived across cultures. Not surprisingly, a steady increase in prevalence rates in recent years in China has coincided with increases in the number of studies that have examined relations between executive functions and ADHD in Chinese children and published in Chinese language journals (Liu & Wang, 2002; Ou, Sun, & Li, 2012; Zhang et al., 2010; Zhou, Luo, & Li, 2005).

One issue addressed by the present research concerns whether effect sizes generated from studies of executive functions-ADHD relations among Chinese children are similar to those found in research with US samples. Societal perceptions of the behaviors that contribute to a diagnosis of ADHD may differ between cultures, leading to variation in the composition of study samples identified using the same diagnostic criteria. Norvilitis and Fang (2005) found that although the same behavioural criteria for a diagnosis of ADHD were used, mental health professionals in China, Indonesia, Japan, and the US rated hyperactivity differently. Notably, they report that Chinese clinicians rated the intensity of hyperactive behavior significantly higher than US clinicians. This finding led the authors to conclude that apparent differences in prevalence rates of ADHD between China and the US may be a reflection of differences in perceptions and tolerance of behaviours that do not conform to societal expectations. If this is the case, the magnitude of ADHD/non-ADHD group differences on measures of executive functions may differ across US and Chinese studies as a function of sampling variation. On the other hand, findings that show effect size estimates are statistically the same across cultures lend tentative support to the idea that the relations between executive functions and ADHD are robust across cultures and across samples that likely differ in severity of ADHD symptomology.

A second issue is related to whether the pattern of relations between different measures of executive functions and ADHD is the same in Chinese and US samples. In a comprehensive meta-analysis of 83 empirical studies, Willcutt et al., (2005a) identified 13 measures of executive functions that were used repeatedly in the research. These measures fell under the categorical descriptions of: response inhibition, set-shifting, verbal working memory, and spatial working memory. The authors also reported effect sizes for measures that represented planning/organization and vigilance. Significant ADHD/non-ADHD (N_{ADHD}= 3,374, $N_{Control}$=2,969) group differences were reported on measures of response inhibition, planning, working memory, and vigilance. On average, effect sizes were in the medium range across studies and the overall effect size reported was .54. The authors concluded that ADHD was significantly associated with several key executive functions; and that a multifactorial model underlies the relationship between executive functions and ADHD. This finding contrasts with earlier meta-analytic reports that included studies focused on a specific executive function domain and measure (e.g., WCST: Romine et al., 2004; Stroop: Homack & Riccio, 2004; Stop signal task: Alderson, Rapport, & Kofler, 2007; Working memory: Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005) that suggested response inhibition, either alone or in combination with secondary effects from other forms of executive functions, was the primary limitation experienced by children with ADHD (Barkley, 1997; Lijffijt, Kenemans, Verbaten, & van Engeland, 2005; Pauli-Pott & Becker, 2011; Sonuga-Barke, Dalen, Daley, & Remington, 2002; Wodka et al., 2007).

To date, a meta-analysis of findings from studies conducted with Chinese samples and published in Chinese language journals has not been published. This is an oversight, particularly in light of developments in the publishing world where databases such as PsycInfo and PubMed now contain studies published in Chinese language journals. As the flow of information increases among nations, further understandings about the association between executive functions and ADHD in culturally diverse samples can be gleaned. Therefore, the aims of the present meta-analytic review are threefold: first, studies not included in Willcutt et al.'s (2005) comprehensive meta-analysis will be added to update findings from North American studies that compare ADHD-non-ADHD group differences in performance on executive function measures. Second, a synthesis of research findings from studies that have compared executive function performances of Chinese children with and without ADHD living in Asia will be conducted. Lastly, a comparison of findings from the two separate meta-analyses will be conducted.

1.2. The Construct and Measurement of Executive Functions

As previously noted, executive functions comprise a set of cognitive processes that contribute to the regulation of behavior to meet future goals. These processes typically involve the ability to inhibit responses, to update and maintain attention in the face of interference, and/or to shift easily between cognitive goals, all of which contribute to efficient use of strategies for planning and general self-regulation (Barkley, 1997, 1999, 2001, 2006; Pennington & Ozonoff, 1996; Schoemaker et al. 2012). While several factor analytic studies have affirmed the independence of the constructs that underlie executive functions after a child reaches the age of 8 years (Lehto, Juujärvi, Kooistra & Pulkkinen, 2003; Miyake et al., 2000), cultural invariance between the constructs tapped by these measures has not been clearly established in the research to date. Comparisons of task-performances between samples from different cultures must be reviewed with necessary caution. In the present review, this issue is addressed by grouping and synthesizing findings from Chinese and North American studies separately.

Notably, measures of executive functions used in this body of research are performance-based tests that are administered in highly standardized conditions (Toplak, West, & Stanovich, 2013). Instructions and the task procedures are carefully controlled so that each child has the same opportunity to respond as all other children involved in the research. Outcomes are measured in accuracy, response time, and/or speeded responding under a time constraint (Toplak, West, & Stanovich, 2013). A review of measures categorized under different constructs associated with executive functions follows.

1.2.1. Response Inhibition

The classic Stroop paradigm (Golden, 1978; Stroop, 1935) usually involves three conditions performed consecutively (word naming, colour naming, and colour-word interference) that require respondents to inhibit prepotent responses in order to correctly complete the task. First, participants are asked to name the colour words printed in black ink (i.e., red, blue, green), and then participants name the ink colour of a series of words that are red, green or blue in colour. Finally, participants are required to name the colour of words printed in ink of conflicting colours (i.e., word RED printed in blue). The final condition creates conflicts between an automatic response (i.e., word reading) and a slower response (i.e., colour naming) with both responses competing for the same cognitive resources. Reaction time and errors from the third condition are the outcomes indicative of response inhibition. Difficulty performing on the Stroop task has been associated with prefrontal cortex dysfunction. In general, colour-word interference is believed to demonstrate the cognitive ability to inhibit stimulus based responses and set shifting (Wecker, Kramer, Wisniewski, Delis, & Kaplan, 2000). The original Stroop test been translated into multiple languages (Chen & Ho, 1986; Delis, Kaplan, & Kramer, 2001; Lee & Chan, 2000; Regard, 1981; Strauss, Sherman, & Spreen, 2006), and computerized versions have been constructed to estimate reaction time by key-pressing or voice response (Hepp, Maier, Hermle, & Spitzer, 1996). The adequacy of the Stroop paradigm to distinguish groups of children with ADHD from groups of children with other childhood disorders was investigated in a review of 18 studies (Homack & Riccio, 2004). Findings showed that on average, individuals with ADHD performed worse, compared to controls, on Stroop tasks (mean weighted effect sizes are 0.50 or greater). However, variability in effects (weighted mean effect sizes ranged from −1.05 to 0.73) was high, indicating that differences in performance on the Stroop measures were not stable, and the Stroop paradigm, in isolation, is not sufficient to discriminate individuals with ADHD from individuals with other clinical disorders.

Stop-signal paradigm (Logan, 1994; Logan, Schachar, & Tannock, 1997) is a computerized assessment that measures cognitive ability to inhibit a response that has been previously initiated. Individuals press a key (go) and stop pressing (stop) in response to a single tone that is a cue to respond. The Stop Signal Reaction Time (SSRT =mean RT on go trials – mean stop-signal delay) is one of the clinical indexes of inhibitory control. Longer stop-signal reaction time (SSRT) reveals weakness in response inhibition might due to deficient attentional processes (Alderson, Rapport, & Kofler, 2007; Lijffijt et al., 2005; Pliszka, Borcherding, Spratley, Leon, & Irick, 1997). In a meta-analysis of 22 studies that focused on ADHD participants using a stop signal task, Alderson et al., (2007) report significant differences between ADHD participants and typical controls on the SSRT with a weighted mean effect size of 0.63.

A *Go/No-Go paradigm* is a computerized task where participants are required to press a certain key in response to a "go" stimulus (i.e. auditory sound, visualized shape) and to suppress a response to a "no go" stimulus. Significant correlations between poor Go/No-Go task performance and hyperactivity/inattention in individuals with ADHD have been documented across studies (Castellanos, Marvasti, Ducharme, Walter, Israel, Krain, & ... Hommer, 2000; Pennington and Ozonoff, 1996; Trommer, Hoeppner, Lorber, & Armstrong, 1988, 1991). Significant differences of commission errors of children with ADHD when compared to controls were consistently found across these studies and suggested difficulties of response inhibition in those with ADHD.

Continuous Performance Test (CPT; Conners, 1995): The CPT requires that children sustain attention to a repetitive task where sounds, symbols or numbers are presented and then respond to targets or inhibit responses to foils that appear. Errors of commission on the CPT tap inhibition processes and omission errors on the CPT are considered as an index for vigilance. Two meta-analyses indicated that performance on the CPT differentiates children with ADHD from non-ADHD controls, as evidenced by weighted mean effect sizes of error of commission that ranged from 0.55 to 0.51 (Frazier, Demaree, & Youngstrom, 2004; Willcutt et al., 2005).

1.2.2. Planning

Planning is defined as the ability to recognize and organize a sequence of steps required to achieve a goal (Lezak, Howieson, Bigler, & Tranel, 2004). Planning involves using information to plan and holding the plan in mind for future goals or problem solving. Poor planning ability is considered an important correlate of ADHD symptoms (Frazier et al., 2004; Papadopoulos, Panayiotou, Spanoudis, & Natsopoulos, 2005; Pennington & Ozonoff, 1996; Qian, Shuai, Chan, Qian, & Wang, 2013; Willcutt et al., 2005;). Willcutt et al., (2005) found that about half of the studies included in their meta-analysis suggested significant impairments of planning in children with ADHD compared to typical controls. Typical measures for planning include the Tower of London/ Hanoi paradigms. The reported weighted mean effect size is 0.51 of Tower of London and 0.69 of Tower of Hanoi.

Tower of London (ToL; Krikorian, Bartok, & Gay, 1994): This task consists of three coloured beads that can be placed on three pegs of unequal height. Participants are required to move and match beads from a standard start position to the prescribed pattern of beads on the pegs following rules. There are 12 problems with increasing difficulty as the task requires from two to five moves. The total score, number of moves, completion time, the number of times rules are broken, and time required to make the first move (initial thinking time) are outcome measures (Li, 2009; Li, Zou, Jing, Tang, & Chen, 2005).

Tower of Hanoi (ToH): Similar to ToL, on the ToH task, participants are required to transform an arrangement of disks into a different configuration with the least possible moves. The total completion time and steps are the dependent variables to assess an individual's ability to plan.

1.2.3. Set Shifting

Set shifting refers to the ability to switch back and forth among various tasks, actions and cognitive sets (Miyake et al., 2000). While impairments in set shifting in children with ADHD compared to control groups have been reported (Lawrence et al., 2004; Seidman et al., 1995; Yao & Li, 2003; Zhou, Luo, & Li, 2005) other studies have not found an association (Goldberg et al., 2005; Piek, Dyck, Francis, & Conwell, 2007; Miller, Ho, & Hinshaw, 2012a). Other reports suggest that set shifting weaknesses are more prevalent in adults, than in children with ADHD (Boonstra, Kooij, Oosterlaan, Sergeant, & Buitelaar, 2010; Halleland, Haavik, & Lundervold, 2012; Rohlf et al., 2012).

Trail Making Test (TMT) from the Halstead-Reitan Neuropsychological Battery (Reitan, 1979; Reitan & Wolfson, 1985).The TMT is commonly used to investigate cognitive flexibility and set shifting. The task involves two parts: Part A and Part B. Part A is often viewed as a preparation task involving visual scanning to connect random numbers following the original numerical sequence. Part B requires tracing a path that shifts between letters and numbers (i.e., 1-A-2-B-3-C). The completion time of the Part B task is the index of functioning of set shifting. Some researchers also use the time to complete the more difficult part B minus the completion time of part A as an index of set-shifting (e.g., Biederman et al., 2004; Qian, Shuai, Cao, Chan, & Wang, 2010). The meta-analyses of TMT Part B reported mean effect sizes ranged from 0.55 to 0.59 (Frazier et al., 2004; Willcutt et al., 2005).

A Chinese version of the Halstead-Reitan Neuropsychological Test Battery for Children (HRNTBC—CR) was developed by Gong (1986). This version is used with children (aged 5-8 years) and with adolescents (aged 9-14 years) in China. As local norms are available, the TMT is also widely used by Chinese researchers to assess set shifting ability in Chinese children diagnosed with ADHD (Ou, Sun, & Li, 2012; Qian, et al., 2010; Shuai, Chan, & Wang, 2011; Shuai & Wang, 2007b; Strauss, Sherman, & Spreen, 2006; Yang et al., 2011).

Wisconsin Card Sorting Test (WCST; Heaton, 1981, 1993) The WCST is one of the most widely used assessments to investigate individual variation in set-shifting in research on children with ADHD (Bidwell, Willcutt, DeFries, & Pennington, 2007; Mullane & Corkum, 2007; O'Brien, Dowell, Mostofsky, Denckla, & Mahone, 2010; Yao & Li, 2003; Zhou, Luo, & Li, 2005). Non-computerized (Heaton, 1993) and computerized versions (Closson, 2011) are available in both English and Chinese. The WCST consists of four stimulus cards that vary on the basis of colour, shape, and number of geometric designs displayed. Response cards with geometric designs also vary according to colour, form, and number. Participants are required to match the response card to one of the stimulus cards. They are not told how to match the cards, but they are told whether the matching rule that they have used in their response is correct. After a certain number of correct responses, the examiner switches to new rules without telling participants. Traditionally, the number of perseverative errors in relation to total errors was considered as the most highly sensitive index of the ability to generate, maintain, and shift cognitive sets for diagnosing children with ADHD (Barkley, Grodzinsky, & DuPaul, 1992). Several meta-analyses that investigated performance on WCST in groups of children with and without ADHD reported mean effect sizes on this measure ranging from 0.35 to 0.46 (Frazier et al., 2004; Romine et al., 2004; Willcutt et al., 2005). A meta-analytic review of 33 studies of children and adolescents with ADHD (Romine et al., 2004) found that although groups of individuals with ADHD performed poorly on WCST, other groups with other clinical disorders (e.g., learning disorder, conduct disorder) performed worse than the ADHD groups.

1.2.4. Working Memory

Working memory involves a dynamic range of complex cognitive processing that requires temporary storage and processing of information (i.e., visual images, spatial or verbal/linguistic information; Baddeley, 1986; Pennington & Ozonoff, 1996). Working memory is associated with other executive functions (e.g., planning, set shifting) and linked to processing in the frontal lobe (Pennington & Ozonoff, 1996). In a meta-analytic review of studies that compared working memory performance in children with- and without ADHD, Martinussen et al., (2005) found significant effect sizes on measures of verbal working memory (ES= 0.43) and spatial working memory (ES = 1.06).

1.2.5. Verbal Working Memory

The Digit Span subtest of WISC (WISC-III/IV; Wechsler, 1991, 2004; Gong & Cai, 1993) is reportedly the most widely used measure of verbal working memory (Huang-Pollock, Mikami, Pfiffner, & McBurnett, 2009; Schuster, 2005). This subtest includes two component tasks: digits forward (DSFW) and digits backward (DSBW). The two tasks require participants to recall the digits in a forward and reverse order. The digits forward test assesses short-term memory, and digits backward assesses verbal working memory. The total number of correctly recalled trials is used as an index for working memory. Chinese researchers normally use the same subtests in the Chinese version of the WISC (C-WISC; Gong & Cai, 1993) for research (Li et al., 2005; Liu & Wang, 2002; Liu & Wang, 2004; Yao & Li, 2003; Zhou et al., 2005).

The *Sentence Span task (Siegel & Ryan, 1989)* is recognized as a more pure and precise measure of verbal working memory. Participants are required to provide the last word for a set of simple sentences read by the examiner. The difficulty is increased from two-sentence sets to six-sentence sets, by adding one more sentence for each level.

1.2.6. Spatial Working Memory

The *Corsi Blocks Test (CBR, Corsi, 1972; Vandierendonck, Kemps, Fastame, & Szmalec, 2004)* is a measure that is used extensively to tap spatial working memory. Nine identical cubes are positioned irregularly on a board. The examiner taps a sequence of blocks and participants are required to repeat the sequence in the same or reverse order. A modified computerized version of the Corsi Block test was developed for the Cambridge Neuropsychological Test Automated Battery (CANTAB).

The Spatial Working Memory test (CANTAB; Cambridge cognition, 1996) is another popular computerized test used to measure spatial working memory (Bidwell et al., 2004; Gau & Chiang, 2013; Goldberg et al., 2005; O'Brien et al., 2010). Each trial requires participants to find a hidden blue "token" from a number of coloured boxes scattered on a touch screen where the colour and positions of boxes change from trial to trial. The numbers of boxes is gradually increased to eight boxes. Total errors and a strategy score are computed by the software as outcomes.

1.3. Potential Moderators of ADHD-Executive Functions Relations

1.3.1. Age

Few studies have investigated the influence of age on executive functions-ADHD relations in children (Gau, Chiu, Shang, Cheng, & Soong, 2009; Lin, Lai, & Gau, 2012). One exception is a meta-analytic review (Pauli-Pott & Becker, 2011) of studies that investigated neuropsychological deficits in preschoolers at risk of ADHD. Findings revealed that delay aversion tasks (e.g., children required to suppress a motivational determined response, for example, to touch an attractive toy) appear to have a statistically significant association with ADHD risk and this association is moderated by the age of the children in study samples. As the age increased, the effects of delay aversion tasks significantly decreased. However, no association between other executive functions with ADHD risk was found.

While executive functions first emerge in early childhood, development of these abilities continues through adolescence. Thus, one possibility is that ADHD/non-ADHD group performance differences on executive function measures will widen over the course of the school years and thus, behavioral symptoms associated with ADHD is also expected to increase with age. Some support for this idea is found in research that shows age is an important predictor of a diagnosis of ADHD, with older children being diagnosed more frequently than younger children (Applegate et al., 1997), and behavioural symptoms associated with ADHD subtypes intensify over children's development (Garon, Bryson, & Smith, 2008; Lahey, Pelham, Loney, Lee, & Willcutt, 2005; Pauli-Pott & Becker, 2011).

1.3.2. Intelligence

Whether intelligence mediates executive function limitations among children with ADHD has been debated (Frazier, Demaree, & Youngstrom, 2004; Schuck & Crinella, 2005; Mahone et al., 2002; Mattison & Mayes, 2012; Tillman, Bohlin, Sørensen, & Lundervold, 2009; Zambrano-Sánchez, Martínez-Cortés, Rió-Carlos, Martínez-Wbaldo, & Poblano, 2010). Mahone et al. (2002) specifically addressed the impact of IQ on measures of executive function in children with ADHD. Essentially, they found that IQ contributed a great proportion of variance in the executive function measures. Moreover, these executive function measures were considered to have a greater ability to discriminate children with ADHD from non-ADHD comparisons in an average IQ range than a superior IQ range. A meta-analysis (Frazier et al., 2004) suggested that individuals with ADHD were significantly differed from control groups on the overall intellectual ability (e.g., FSIQ). They also suggested that some intellectual deficits might contribute to executive dysfunction of ADHD. In studies of typically developing children and adults, performance on measures of executive functions, particularly working memory tasks, has been associated with individual variation in fluid intelligence (Mattison & Mayes, 2012; Tillman, Bohlin, Sørensen, & Lundervold, 2009). However, Dennis et al. (2009) found group differences in IQ did not explain significant group differences in performance of children with ADHD on measures of executive functions. Willcutt et al. (2005) also reported that IQ was not a significant moderator of effect sizes in a meta-analysis of studies that investigated ADHD/non-ADHD group differences in executive functions.

1.3.3. Other Sample Characteristics

Other potential moderators that may influence the magnitude of effect sizes found when comparing ADHD/non-ADHD groups on measures of executive functions (Pennington & Ozonoff, 1996) include: diagnostic criteria used to identify ADHD (i.e., DSM-III, DSM-IV, DSM-IV-TR) and sampling method (i.e., clinical referral, school identification, or a combination of clinical, school referral). Whether or not the sample children are taking psycho-stimulant medication may also influence the magnitude of effect size differences found among studies. Notably, Atomoxetine and Methylphenidate are the two most widely prescribed medications for ADHD in both North America and China. Kempton et al. (1999) found that relative to typically developing controls, medication naïve ADHD children showed depressed performance on most executive function tasks of CANTAB (i.e. except pattern recognition), whereas children who had a history of taking medication performed worse only on a spatial working memory task. Further Semrud-Clikeman, Pliszka, and Liotti (2008) found children with ADHD who had been prescribed stimulant medication and who were withdrawn from medication 24 hours prior to assessment performed similarly to typical controls, and better than medication naïve ADHD children on Stroop interference and attention tasks.

1.3.4. Publication Status

Whether unpublished dissertations should be included in meta-analytic reviews in order to avoid publication bias is frequently debated in the literature (Coyne, Hagedoorn, & Thombs, 2011; Moyer, Schneider, Knapp-Oliver, & Sohl, 2010). One recent meta-analytic review found little difference in methodological adequacy between published and unpublished dissertations in studies of cancer and suggested that unpublished dissertations be included in meta-analyses (Moyer et al., 2010). On the other hand, Coyne et al. (2011) suggest that inclusion of unpublished dissertations in meta-analyses without critical analysis of study quality should be avoided.

1.3.5. Executive Function Tasks

One trend in today's research is to obtain data from computerized methods. An important issue concerns the psychometric equivalence between computerized and non-computerized measures when investigating the executive functions of children with ADHD. Some measures were originally developed as computer-based task (i.e., Stop-signal task, Continuous Performance Test, CANTAB), and some are manual based measures that were changed to computerized versions (i.e., Wisconsin Card Sorting Test, Stroop colour word test).

1.4. Research Questions

Three research questions guide the present review:

a. What is the magnitude of performance differences between children with and without ADHD on measures of inhibition, planning, set shifting, working memory, and vigilance within North American studies and Chinese studies?
b. Is the pattern of effect sizes observed within Chinese studies comparable to those found with North American studies?
c. Is variation in effect sizes moderated by sample characteristics (i.e., age, IQ, diagnostic criteria), study characteristics (publication status) or the modality of executive function measure (i.e., computerized versus non-computerized tasks)?

2. Methodology

2.1. Selection of Studies

Studies conducted on groups of Chinese- or English-speaking children with or without ADHD were located by searching relevant databases using key terms in English and Chinese such as: ADHD + child*", "注意缺陷多动 + 儿童", "executive function", "执行功能", "inhibition", "抑制功能" , "working memory", "工作记忆". PsycINFO, MEDLINE, and ERIC databases were used to locate both Chinese and English studies. To avoid redundancy with previous meta-analyses (Homack & Riccio, 1004; Huang-Pollack and Nigg, 2003; Willcut et al., 2005), the search was limited to the years 2003 – 2012.China National Knowledge Infrastructure (CNKI), WanFang Data, and China Chongqing VIP Information (CQVIP) databases were used in addition, and exclusively, to find studies conducted on samples of Chinese children. CNKI is the largest comprehensive database in China. Reference lists in selected publications were also searched to locate additional studies on this topic. Using these descriptors, the search yielded a total of 1,396 citations from English language publications and 224 citations from Chinese language publications.

The abstract of each citation was read in full and studies were excluded if: a) no comparison group was included; b) sample children were not from age range 3-16 years; c) the study was not on the topic of executive functions in children with ADHD; d) the study was not conducted in the native language of the child (i.e., either Chinese or English); and e) the study was not conducted in the country of the child's cultural origin. This reduced the total number of articles to 106 English language publications and 76 Chinese language publications.

Each article was then read in full. To be included in the meta-analysis, studies reviewed met the following selection criteria with 100% certainty:

1. Identification of sample children with ADHD was based on the Diagnostic and Statistical Manual of Mental Disorders: third edition (DSM-III-R, American Psychiatric Association, 1987), fourth edition (DSM-IV, American Psychiatric Association, 1994), or the fourth text revised edition (DSM-IV-TR, American Psychiatric Association, 2000).
2. All participants with ADHD were either diagnosed by a licenced psychologist or psychiatrist at the time of the study or were enrolled in special programs for children with ADHD that required a formal diagnosis by a licensed psychiatrist or psychologist upon enrollment in the program.
3. Relative to the norming sample, standardized scores on a measure of intelligence of individual children in both ADHD and comparison groups fell in the average range (i.e., > 70 standard score points).
4. Performance on executive function measures was calculated for both an ADHD group and a comparison group of typically developing children.

Sufficient data had to be available for calculation of effect sizes on measures of executive functions. This included: group means, standard deviations, F- values, t-values, and correlation coefficients.

Thirty studies of English-speaking children with ADHD met these inclusion criteria. Eighteen findings were published in English language journals and twelve were in dissertations from North American universities. Forty-three studies of Chinese-speaking children with ADHD that met the inclusion criteria were published either in Chinese language journals (n=24), English language journals (n=11) or as dissertations at Chinese universities (n=8). When several studies of ADHD children were conducted by the same research team and findings reported in both English and Chinese language journals, the first author of the study was contacted by email to confirm that the data used in each study were independent.

2.2. Study Characteristic, Outcome Measures, and Potential Moderator Codes

2.2.1. Study Characteristic Codes

The following codes were created as a means to describe the sample characteristics for each study: a) age (in months); b) sample size; c) IQ status (average

FIQ); d) documented ADHD subtype (ADHD-H with hyperactivity; ADHD-I inattentive, ADHD-C combined hyperactivity and inattentive); e) DSM Diagnostic criteria (DSM-III-R; DSM-IV; DSM-IV-TR); f) procedures and referral sources (clinic, school, or clinic, school, community combined); g) medication control of subjects (i.e., whether stimulant medication had stopped at least 12 hours before testing; whether psychoactive medicated participants were excluded from the study); h) publication status (journal articles, dissertation).

2.2.2. Outcome Measure Codes

Each measure of executive function was assigned into a descriptive category. Table 2 shows the neuropsychological tasks and outcome measures that were included in each category.

Table 1. Descriptions of EF Tasks in Meta-Analysis

Executive Function Construct	Neuropsychological task [a]	Outcome Measure
Response Inhibition: the ability to inhibit an initial response to a stimulus and stop an ongoing response.		
Press the key/bar when target sequence (all letters except 'X') appears and do not respond to the specified letter ('X').	• Continuous Performance Task (CPT)	a) Hit reaction time to target stimuli b) Total number of commission errors: response to a sequence other than the target sequence.
Press key when target appears('go' trial) and do not to press when an auditory tone was presented('stop' trial)	• Stop-signal Task paradigm	a) SSRT: Subtraction of the mean total time elapsed between a stop signal and response from the mean response time on 'go' trials.
Complete three conditions: 1) read a page of colours; 2) read a page of colour words printed in black ink; 3) read a page of colour words printed in opposing colours and names the colour instead of the word.	• Stroop Colour Word Test (SCWT) paradigm • D-KEFS Colour-Word Interference Condition3 (DCWI3)	a) Total reaction time in the interference condition; b) Total number of errors in the interference condition: mistakenly naming the words instead of the colour during interference section; c) Stroop interference scaled score: automatically computed by D-KEFS based on errors and total time to complete
Provide speeded response to "go" trials by press button/key	• Go/No-Go Paradigm	a) Total number of commission errors: fail to inhibit the response to the "no-go" stimulus; b) Percentage of total number of commission errors

Executive Function Construct	Neuropsychological task [a]	Outcome Measure
Vigilance : the ability to maintain attention and alertness over prolonged periods of time		
Provide speeded response to “go” trials by press button/key	• Continuous Performance Task	a) Total number of omission errors: fail to respond to the "go" stimulus
	• Go/No Go Paradigm	a) Total number of omission errors: fail to respond to the “go” stimulus; b) Percentage of total number of omission errors
A target number chosen by examinee (i.e., 7)in a randomized array of digits from 0 to 9 printed on a paper 1) To delete all the target numbers(i.e.,7); 2) to delete all the numbers right before the target number(i.e., 1,4,~~2~~,7,4,5,~~6~~,7); 3) to deleted a specific number right before the target number(i.e., delete 8 in 1,6,7,3,5,~~8~~,7)	• Digit/Number Cancellation Task (NCT)	a) Total score: total number of correct minus total number of commission errors (delete the number but not the target number) then minus half of the number of omission errors(fail to delete the target number); b) Percentage of errors: (commission errors + omission errors)/2)/total number of correct answers*100
Planning: the ability to produce rule-governed behavior, engage in description, reflection, generation of rules and meta-rules.		
Reproduce the given complex figures as good as one could	• Rey-Osterrieth Complex Figure Task (ROCF) Copy condition	a) Composite score (0-6) based on the time for copying and the accuracy of copying figures
Move disks, varying in size from small to large, across three pegs (five pegs in DKEFS) to build a designated tower in the fewest number of moves possible	• Tower of Hanoi/ London (ToH / ToL)	a) Total completion time of test; b) Total number of moves; c) Initial thinking time of planning; d) Total times of breaking rules
	• D-KEFS Tower (DTower)	a) Total achievement score: based on number of moves to build the tower, rule violations, completion time and final tower correctness composited and generated by DKEFS software
Re-arrange three balls in the bottom display to match the goal arrangement in the top display	• Stocking of Cambridge (SOC)	a) Minimum number of moves to solve problem; b) Initial thinking time: reaction time taken to select the first ball for the problem.
Set Shifting/Flexibility: the ability to swap between different tasks or rules in a timely and accurate way.		
Part B: connecting numbers to letters in ascending and alphabetic order(i.e.,1-A-2-B) as quickly as possible	• Trail Making Test (TMT) • D-KEFS Trail Making Condition 4 (DTMC4)	a) Completion time of finishing the Part B; b) Total number of errors in Part B: connects number to letters incorrectly b) Shift time=completion time of Part B-Part A;
Sort 128 of cards to match either the colour, form, or number of shapes on four stimulus cards.	• Wisconsin Card Sorting Test (WCST)	a) Perseverative errors: errors that reflect difficulty shifting to a new rule when provided with feedback indicating that the previous rule is no longer correct; b) Percentage of perseverative errors

Executive Function Construct	Neuropsychological task [a]	Outcome Measure
Observe the combination of simple colour-filled shapes or white lines, and must learn which one is correct of each task by touching it and judge the pattern with feedbacks that indicate which stimulus is correct in two dimensions.	• CANTAB Intra-dimensional/Extra-dimensional Shifts (ID/ED)	a) Extra-dimensional stage shift errors: numbers of errors made in the EDS stage.
Working memory (verbal/spatial): "the capacity to hold a verbal or spatial mental representation in mind to guide behavior" (Baddeley, 1986).		
Digit Span: immediately reproduce a series of digits in the order and reverse of the order (DSBW) that they were presented.	• Digits Backward (DSBW)[c] • Digit Span (DS)[c]	a) Standardized score: based on the norm in Wechsler Intelligence Scale for Children(WISC-III/IV)
Repeat the last word for a set of simple sentences read by examiner then reproduce each word that he or she provided after all sentences are completed	• Working Memory Sentence Span task	a) the number of sets completed correctly
Count aloud the number of yellow dots on a series of cards, recall in order the number of yellow dots that appeared on each of the cards in the set	• Counting Span task	a) Total number of correct sets
Spatial Working Memory		
Find all the prizes that are hidden in the boxes in the fewest moves	• Self-ordered Pointing(SOP)	a) Total number of repetition errors
Remember the location of a target in a grid	• Spatial Span Test (SST) paradigm	a) Total number of correct response
White squares are displayed on a screen and some briefly change colour in a variable sequence. Required to remember and touch the same order in which visual stimuli are presented.	• CANTAB Spatial Span (SSP)	a) Span length: the longest sequence successfully recalled; b) Total number of errors:the number of times an incorrect box was selected.
Search spatial locations to find tokens while remembering not to return to any locations where tokens were previously found	• CANTAB Spatial Working Memory (SWM)	a) Total errors:between errors + within errors – double errors b) Between search error:returning to an empty box where a target was already been found; c)Within-search error:a box previously opened and shown to be empty earlier in the same search sequence; d)Double error: could be categorized as both a within and a between error c) Strategy score: from the number of searches that start from the same location

Executive Function Construct	Neuropsychological task [a]	Outcome Measure
Observe a sequence of up to nine identical spatially separated blocks tapped and then repeat tapping the sequence in order	• Corsi Blocks Test (CBT)	a) Total number of the correct trials
After a short delay of copy condition, participant will be required to reproduce the figure from memory; After a longer delay (max. 30 mins), participant will be asked to draw the figure form memory.	• Rey-Osterrieth Complex Figure Immediate and Delay recall condition (ROCF)	a) Two composite scores based on structure and detail (18 specific design elements, score from 0-6) of each copy finished in Immediate and Delay conditions
Complex[b]: requires working memory, inhibition, and set shifting in one task		
Switch back and forth between naming the dissonant ink colours and reading the words.	• D-KEFS Colour Word interference condition 4:Inhibition/Switching (DCWI4)	a) Composite scaled score that evaluated and generated by DKEFS computer system based on completion time, corrected and uncorrected errors; b) Completion time of condition 4
Generate words, alternating between two different semantic categories (i.e.,naming fruits and pieces of furniture) as quickly as possible.	• D-KEFS Verbal Fluency Condition (DVF) 3:Category switching	a) Standard score of total number of correct words generated by DKEFS software b) Total switching accuracy: quantified by cumulative percentile of correct response

a. References for additional information about each task: CPT (Conners, 1995; Gordon, 1983), SSRT (Logan, 1994; Logan, Schachar, & Tannock, 1997), SCWT paradigm(Golden, 1978; Lee & Chan, 2000; Stroop, 1935), D-KEFSCWI3, SCWI4, DTo, DTMC4 (Delis, Kaplan, & Kramer, 2001),Go/No-Go paradigm (Harris et al., 1995; Laboni, Douglas, & Baker, 1995; Mostofsky, Newschaffer, & Denckla, 2003), ROCF (Osterrieth, 1944), ToL paradigm (Culbertson & Zillmer, 1998, 2001; Krikorian, Bartok, & Gay, 1994), ToH (Kopecky, Chang, Klorman, Thatcher, & Borgstedt, 1975, 2005), SOC (Shallice, 1982),TMT(Reitan, 1979; Reitan & Wolfson, 1985), WCST(Heaton,1981, 1993), CANTAB ID/ED Shifts, SSP,SWM, SOC (Cambridge Cognition, 1996), DSFW,DSBW (Wechsler, 1991, 2003; C-WISC, Gong & Cai, 1993; Wechsler memory scale-Chinese version(WMS), Gong& Cai, 1989), CBT (Vandierendonck, Kemps, Fastame, & Szmalec, 2004), NCT (Pascualvaca et al., 1997), Sentence Span task(Siegel & Ryan, 1989), Counting Span test (Dunn & Markwardt, 1970). **b**. Complex executive functions were assessed by D-KEFS CWI4 and VFC3 tests. DCWI4 and VFC3 integrated multiple functioning testing which including working memory, set shifting, and inhibitory control (Peden, 2010; Wodka et al., 2008a, 2008b). **c.** DSFW and DS subtest of WISC-III and WISC-IV were used in North American and Taiwanese studies. In Chinese studies, the subtests of C-WISC or WMS were conducted. Raw score or the number of highest correct trial was recorded from C-WISC, scaled score coded from WMS.

2.3. Study Characteristics

In total, 73 studies (North American, n= 30; Chinese n=43) satisfied selection criteria for inclusion in the analysis. As shown in Appendix A, all Chinese studies adopted DSM-IV diagnostic criteria while 24 of the 30 (80%) North American studies applied DSM-IV. Three North American studies (16.7%) used DSM-IV-TR and one study (3%) used DSM-III-R. The average age of participants was 128.4 months (SD =334.08;

range =56.52-188.16 months) in North American studies and 124.8 months (SD =292.32; range =94.8-152.16 months) in Chinese studies. Two North American studies included samples of children aged 3 to 6 years (Mahone, Pillion, Hoffman, Hiemenz, & Denckla, 2005; Youngwirth, Harvey, Gates, Hashim, & Friedman-Weieneth, 2007) and 3 North American studies drew samples of children aged 8 to 12 years (Closson, 2011; Edmonds, 2007; Hummer et al., 2011). Twenty-four of the 30 North American studies (80%) included children who were stimulant medicated. Thirty-six of 43 Chinese studies (84%) included children who were required stop using stimulant medicine prior to the research took place. However, the information of stimulant medication usage was not provided within the studies. In addition, a number of Chinese studies required that ADHD participants had no history of medication usage or treatment for ADHD as inclusion criteria (12/43 studies, 28%). The average IQ of participants in North American studies was 105.54 (SD=6.04; range=91.85-116) and 104.29 (SD=5.78; range=85.07-116.27) for participants in Chinese studies. Most Chinese studies recruited ADHD participants from psychiatric clinics or hospitals (79% of Chinese studies, 27% of North American studies) whereas most North American studies recruited ADHD participants from multiple resources (57% of studies; i.e., school, community center, support groups).

2.4. **Moderators**

In order to address specific research questions, specific moderator variables included a) the diagnostic criteria employed (DSM-III-R/DSM-IV/DSM-IV-TR), b) sampling method (clinical, school, or clinic, school and community combined), c) medication control (yes/ no) and d) publication status (published/ dissertation). Willcutt et al. (2005) found in their meta-analysis of studies that investigated EF in children with ADHD that sampling method had no detectible influence on effect size variation. Sampling procedures were coded in the present study. ADHD subtypes (combined, inattentive, hyperactive/impulsive) and other comorbid disorders (i.e., Learning Disability, LD; Oppositional Defiant Disorder, ODD; Disruptive Behavior Disorder, DBD; Reading Disability, RD) were also coded as potential moderators. Furthermore, although all samples from North America included children with ADHD who had taken medication, samples in the Chinese studies included children who had never been prescribed a regime of medication. Stimulant medication usage for ADHD has been associated with performance on EF measures; therefore, this potential moderator variable was coded as controlled if medication was discontinued at least 15 hours prior to the administration of EF tasks, not controlled, or no information provided. Publication status (journal, dissertation) was also coded as a potential moderator because it could represent one aspect of publication bias.

Socioeconomic status (SES) could not be coded because Chinese studies did not report sufficient data. Although SES has been shown to be a moderator of EF among North American children, the influence of SES as a moderator variable on EF could not be determined for this synthesis.

2.5. Analytic Strategy

All data calculations and analysis were conducted using the Comprehensive Meta-Analysis (CMA, version 2.2) program (Borenstein, Hedges, Higgins, & Rothstein, 2005). All effect sizes and standard errors calculated in this study were based on reported means and standard deviations. All effect sizes are reported by using Hedges' *g* (Hedges, 1981). As studies generally vary in size, effect sizes from each study were weighted by their inverse variance ($w=1/SE^2$), so studies with larger samples would be given more weight (Hedges & Olkin, 1985). Studies with less variation were assigned more weight.

The standardized mean difference from studies that used two independent groups is estimated by Cohen's *d* as follows: (Let n_1 and n_2 be the sample size of two groups. Let $\overline{X_1}$ and $\overline{X_2}$ be the sample means for the two groups. S_1 and S_2 are the standard deviations in the two groups)

$$d = \frac{\overline{X_1} - \overline{X_2}}{S_{within}}$$

$$S_{within} = \sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}}$$

The variance of *d* is given by

$$V_d = \frac{n_1 + n_2}{n_1 n_2} + \frac{d^2}{2(n_1 + n_2)}$$

The standard error of *d* is

$$SE_d = \sqrt{V_d}$$

Cohen's *d* has a bias to overestimate the standard mean differences. Hedges' *g* use a correlation factor J to remove this bias,

$$J = 1 - \frac{3}{4df - 1}$$

Where *df* = degrees of freedom.

Then the Hedges' *g*, the variance of *g*, and the standard error of *g* can be converted from Cohen's *d* as follows.

$$g = J \times d, V_g = J^2 \times V_d, SE_g = \sqrt{V_g}$$

The precision index bounded for each effect size was also reported at a 95% confidence level. According to Cohen (1988), a weighted mean effect sizes of .30 represents a small effect, .50 and .80 are benchmarks of medium and high effects.

Effect sizes for multiple EF measures were found for each study. To satisfy requirements for study independence and to allow for comparison of results across studies, a mean effect size for each domain of EF (response inhibition, planning, set shifting, verbal and spatial working memory, vigilance) was calculated for each study. Heterogeneity tests were conducted to describe the variation in effect sizes within EF domains across studies. The Q statistic, *p* value, I^2 statistic (the percentage of true variation contributed to total variation; I^2 = (Q-*df*) / Q × 100%) and corresponding 95% confidence intervals were reported as descriptive indices of variance. A non-significant Q value is interpreted as the variance in effects is due to sampling error exclusively; whereas a significant Q value suggests that differences in the effects represent meaningful variance. The benchmark of I^2 can be divided into three ranges, 25%, 50% and 75%, considered as low, moderate and high proportion of variation (Higgins, Thompson, Deeks, & Altman, 2003).

As Borenstein, Hedges, Higgins, & Rothstein (2009) point out, the significance of the *p* value cannot be considered as sole verification of heterogeneity due to the influence of low power of some studies. In the current meta-analysis, inspection of the Forrest plot and the homogeneity test results (see *Appendix B*) suggest that the Chinese studies exhibited heterogeneity in effects ($p<0.001$, $Qt=105.77$, $I^2=60.29$), and the North American studies showed a relatively homogenous effect ($p=0.7$, $Qt=25.33$, $I^2=0$). Due to the heterogeneity in Chinese studies, a random effects-model was determined as most appropriate. To facilitate comparison between models, the North American studies were also submitted to random effects modelling procedures. A random effects model has some advantages over a fixed effects model, such as more balanced weight assigned on studies, a wider confidence interval and a reasonable *p* value.

2.5.1. Moderator Analyses

A mixed-effects model with moments to moments estimation, as advocated in Borenstein et al., (2009), was employed to explore the differences in subgroup effect sizes and in categorical moderators (i.e., sampling method, publication status, medication control, diagnostic criteria.) This approach utilizes a random effects model within subgroups and a fixed effect model across subgroups. Sufficient information was found to consider that the estimates of variance among subgroups of children identified with specific ADHD subtypes was precise. However, insufficient information was available about subgroups of children identified with co-morbid disorders, suggesting that comparison of effect sizes may be imprecise.

The influence of continuous moderator variables (IQ, age) on ADHD-comparison group differences in executive functions was explored using meta-regression analyses as described in Borenstein et al. (2009). A random effects model that considers the variance within studies in addition to the variance between studies was used on the full set of studies.

Moderator selection was based on a sufficient ratio of studies (at least 10 for each covariate) in the meta-analysis to yield meaningful conclusions (Borenstein et al., 2009). Meta-regression analyses and Q tests were used to estimate the impact of between-group differences of age, sampling method, diagnostic criteria, medication control, and cognitive impairment in ADHD children.

2.5.2. Outliers

In order to eliminate objective coding decisions and the influence of observed outliers on the pooled results, before the systematic review a sensitivity analysis was performed. Visual inspection of Forrest plots were used to identify potential outliers for each measure within studies.

In the North American collection, there was one outlier found on the Digit Span outcome measure, possibly due to a small sample size (Naidoo, 2007).The obtained effect was 4.1 SD above the sample mean (g_{DS}=1.78, SE=0.4, g_{mean}=0.56, SD=0.3). The impact of this outlier on the mean effect size of all studies (g=0.53, SE=0.03, CI_{95}= 0.47, 0.60, Q=25.33) was minimal. When this outlier was eliminated (g=0.53, SE=0.03, CI_{95}= 0.46, 0.59, Q=22.8), the Q statistic remained comparable, therefore, the effect size was left in the analysis (Hedges & Olkin, 1985). Effect sizes ranged from 0 to 1.78 (all set as positive direction) with 91 effect sizes below the sample mean and 78 above the sample mean.

In the Chinese collection, two effect sizes were confirmed as outliers (at least 4 standard deviations above the sample mean; g_{mean}=0.65, SD=0.61) and were excluded from the analysis (Lipsey & Wilson, 2001). Two outliers were obtained on the Trail Making Test from the same study (Qian et al., 2010). The first outlier was obtained for the ADHD group and was 10.14 SD above the sample mean (g=6.84, SE=0.37); the second outlier was obtained for the ADHD+ODD group and was 7.6 SD above the sample mean (g=5.29, SE=0.33).

These outliers were excluded from the effect size distribution and the SE of overall effect size dramatically decreased. Within the Chinese studies, the I^2 was decreased from 92.74 to 60.29, and remained statistically significant, and the Q value was reduced from 592.11 to 105.77 and remained statistically significant. The effect sizes ranged from 0 to 2.59 (all set as positive direction) with 172 effect sizes below the sample mean and 106 above the sample mean after eliminating 2 outliers.

2.5.3. Publication Bias

Publication bias can be investigated by using various approaches that include: 1) visual identification based on funnel plot and Egger's regression test (Egger, Davey Smith, Schneider, & Minder, 1997) of sample and summary effect sizes; 2) Rosenthal's and Orwin's Fail-safe N (Orwin & Boruch, 1983; Rosenthal, 1979); and 3) Trim and Fill test (Duval & Tweedie, 2000a, 2000b).

In the North American studies, the funnel plot showed a relatively symmetric distribution about the mean effect size with some studies slightly missing on the left edge. This was confirmed by the result of the *p* value of Egger's test, which was not statistically significant (bias=0.29, $p>.05$, CI_{95}=-0.61, 1.20). The result of Rosenthal's fail-safe N indicated that there would need to be 1,897 studies added to the analysis for the effect to become statistically non-significant. Orwin's test allows us to determine a specific criterion of overall effect other than zero when calculating the number of additional studies that would be needed. Orwin's result suggested that we would need to add 50 studies to bring the overall Hedge's g under a small effect size (0.2). To explore the best estimate of the unbiased effect size, the Trim and Fill test provides us with an adjusted effect size (g_{trimed}=0.52, CI_{95}=0.46, 0.58, Q=31.96) after 2 value was trimmed and filled.

In the Chinese studies, visual inspection of the funnel plot showed an asymmetric distribution about the mean effect sizes with some studies shifted towards the right. This was confirmed by result of Egger's test that the *p* value (bias=1.73, $p<0.01$, CI_{95}=0.74, 2.71) was statistically significant. The result of Rosenthal's fail-safe N indicated that there would need to be 6,238 studies added to the analysis to make the effect become statistically non-significant. Orwin's test suggested that we would need to add 75 studies to bring the overall Hedge's g under a small effect size (0.2). To explore the best estimate of the unbiased effect size, the Trim and Fill test provides us an adjusted effect size (g=0.48, CI_{95}=0.44, 0.52, Q=204.80) after 11 values were trimmed and filled. Taken together, these findings suggest that the effect sizes from North American collection of studies showed less publication bias than the Chinese collection.

3. Results and Discussion

In this section, results of meta-analyses of North American and Chinese studies are reported and discussed. First, an overview of the study characteristics is presented. Then, a mixed-model approach was used to partition the variance and examine the heterogeneity of effects found in within North American studies and in Chinese studies (Borenstein et al., 2009; Wood & Eagly, 2009). That is, for each corpus of studies, a fixed effects model was used to combine subgroups of studies and to examine the amount of variance explained by the moderators, and a random effects model was used to combine studies within subgroups.

The literature search yielded 73 studies (North American: 30; Chinese: 43) that together resulted in a total of 449 effect sizes (North American: 169; Chinese: 280). The North American studies sampled a total of 3711 school-aged children between the ages of 3 and 16 years (ADHD n =1,848, Control n =1,863) and the Chinese studies involved 6132 children in the same age range (ADHD n =3,442, Control n =2,690). The majority of studies (18/30, 60%) of North American children with ADHD were published in English-language peer-reviewed journals, and the remaining studies (12/30, 40%) were dissertations from English-language universities. The majority of studies (24/43, 56%) of Chinese children with ADHD were published in Chinese-language peer-reviewed journals, some studies were published in English-language peer-reviewed journals (11/43, 26%) and the remaining studies (8/43, 19%) were reported in dissertations from Chinese-language universities.

3.1. Overall Effect Sizes

As shown in Table 2, the magnitude of the overall mean effect size on executive functions for North American (g =0.53, SD=0.03, range =0.45 to 0.64) and Chinese studies (g =0.61, SD=0.03, range= 0.40 to 0.78) was moderate, which suggests that on average, Chinese and North American children with ADHD perform worse than their peers without ADHD on executive function tasks. This finding is consistent with the moderate range in effect sizes (ES = .46-.69) obtained from Willcutt et al.'s (2005) meta-analysis of studies conducted prior to 2004 on executive functions and ADHD (N_{ADHD}=3734, $N_{Control}$=2969). Although mean effect size differences between North American and Chinese studies appears to be greater on Response Inhibition, Set Shifting, and Vigilance; these differences were not statistically significant, (Q_b (1) < 3.2; all p's > .05). Notably, the proportion of studies that found significant differences between ADHD children and their non-ADHD peers on Planning was limited in both North American and Chinese samples, which resulted in smaller overall effects in this domain. Moreover, only North American studies used complex measures of executive functions to assess ADHD/non-ADHD performance differences. In addition, the considerable heterogeneity in the variance of effects observed on executive function tasks obtained among Chinese studies compared to North American studies may indicate that although mean effect sizes are comparable across the two corpuses of studies, substantive differences may exist in how ADHD is conceptualized in each culture. In the following analyses, the influence of executive function tasks and other factors that potentially moderate variance in effect sizes is compared within and between Chinese and North American studies.

Table 2. Overall Mean Effect Sizes: Comparison of Chinese and North American Corpuses

Executive functions	Chinese[a]	North American[a]	k^g(CH/NA)	$Q_{between}$	P	Willcutt et al.(2005)[b]
Response Inhibition	0.65[h]***	0.54[h]***	25/25	1.97	0.16	0.61/0.51[c]
Planning	0.40[h]***	0.47***	9/11	0.43	0.51	0.69/0.51[d]
Set Shifting	0.59[h]***	0.45***	22/15	3.20	0.07	0.46[e]
Verbal Working Memory	0.58[h]***	0.52***	18/10	0.35	0.56	0.55
Spatial Working Memory	0.62***	0.60***	13/6	0.05	0.82	0.63

Executive functions	Chinese[a]	North American[a]	k[g](CH/NA)	$Q_{between}$	P	Willcutt et al.(2005)[b]
Vigilance	0.78***	0.64***	6/10	0.79	0.37	0.64[f]
Complex		0.47***				
Overall	0.61***	0.53***	43/30	2.55	0.11	

a. Weighted mean effect sizes (Hedge's g); b. Weighted mean effect sizes (Cohen's d); c. Willicutt et al. (2005) reported effect size based on measure: Stop Signal Reaction Time/commission errors on Continuous Performance Task d. ES based on Tower of Hanoi/Tower of London; e. ES based on Wisconsin Card Sorting Task; f. Omission errors on Continuous Performance Task; g. number of studies. h. indicates significant heterogeneity of effect sizes for reasons other than sampling error.*p<0.05, **p<0.1, ***p<0.001.

3.1.1. Executive Function Domains: North American Studies

As reported in Table 3, the magnitude of mean effect sizes across executive function domains was moderate and ranged from g= 0.45 (Set Shifting) to 0.64 (Vigilance). Heterogeneity in the magnitude of effects obtained within executive function domains was significant only for Response Inhibition ($Q_w(25)$ =39.58, p<0.05, I^2=39.37), which indicates that 39.37% of the variance in Response Inhibition could be explained by study-level covariates and 60.63% of the variance was within-studies random error.

Table 3. Effect Sizes across Executive Function Domains: North American Studies

Study	ADHD/TD(n)	Effect Size(g) of the Difference Between Groups						
		Inhibition	Planning	Set shifting	Verbal WM[a]	Spatial WM[a]	Vigilance	Complex[a]
Alford (2006)	30/30	0.68***					0.74*	0.81**
Babb et al. (2010)	22/58			0.60*				
Bidwell et al. (2007)	332/266	0.64***		0.59***	0.59***	0.72***	0.54***	
Biederman et al. (2004)	173/196	0.60***		0.39***				
Cantrill (2003)	28/28	1.07***						
Semrud-Clikeman et al. (2010)	49/32	0.16	0.23					0.21
Semrud-Clikeman et al. (2008)	39/39	0.66***						
Closson (2010)	25/25		0.20	0.38				
Huang-Pollock.et al. (2009)	56/36	0.52***	0.79***		0.40*			
Edmonds (2007)	29/15	1.29***	0.12				1.08***	
Garaas (2007)	27/ 30	0.63*	0.28	0.47	0.67*		1.01***	
Goldberg et al. (2005)	21/32	0.12	0.34	0.31		0.44		
Hale et al. (2009)	64/42			0.52**				
Hummer et al. (2011)	25/25	0.45			0.35			
Karalunas &Huang-Pollock (2011)	45/46	0.88***						
Loftis (2004)	37/39	0.50*	0.74***	0.57**		0.53*		0.45*
Mahone et al. (2005)	40/40	0.51*				0.44	0.81***	
Martel (2009)	168/144	0.47***		0.21				
Miller et al. (2012b)	137/86	0.15			0.42**		0.44**	

Study	ADHD/TD(n)	Effect Size(g) of the Difference Between Groups						
		Inhibition	Planning	Set shifting	Verbal WM[a]	Spatial WM[a]	Vigilance	Complex[a]
Mullane & Corkum (2007)	15/15	1.02***		0.40				
Naidoo (2007)	34/17				0.94***			
O'Brien et al. (2010)	56/90	0.39*	0.39*	0.22	0.32	0.42*		0.52**
O'Donnell (2004)	56/31	0.27			0.52**		0.62***	
Peden (2010)	32/37	0.55*	0.95***	0.77**			0.54	0.76**
Schuster (2005)	30/29			0.51	0.00			
Walkowiak (2008)	40/20	0.79***	0.35					0.39
Willcutt et al. (2005b)	113/151	0.67***		0.53***	0.72***	0.57***	0.66***	
Wodka et al. (2007)	43/72	0.44*						
Wodka et al. (2008a, 2008b)	54/69	0.62***	0.56**	0.27				0.39*
Youngwirth et al. (2007)	28/123	0.34					0.85***	
Weighted mean effect size(g)		0.54h***	0.47***	0.45***	0.52***	0.60***	0.64***	0.47***
±95% confidence interval		0.45,0.64	0.31, 0.62	0.37, 0.53	0.39, 0.65	0.50, 0.71	0.53,0.74	0.32,0.62
Number of studies(%) that found a significant group difference (p<0.05)		19/25 76%	5/11 45%	7/15 47%	7/10 70%	4/6 67%	10/10 100%	5/7 71%
Homogeneity Index: *p* value		0.02	0.16	0.42	0.12	0.51	0.35	0.5
Homogeneity Index: Q_w		39.58	14.19	14.41	14.07	4.28	10.02	5.32

a. complex executive functions that involved measuring Verbal WM, Verbal Working Memory; Spatial WM, Spatial Working Memory by one task. Tasks of D-KEFS: Colour Word interference condition 4: Inhibition /Switching (DCWI4) and Verbal Fluency Condition (DVF) 3: Category switching; h. indicates significant heterogeneity of effect sizes for reasons other than sampling error. *p<0.05, **p<0.1, ***p<0.001.

3.1.2. Executive Function Domains: Chinese Studies

Table 4 shows that the magnitude of mean effect sizes obtained for each executive function domain tapped by tasks used in Chinese studies fell in the small (ES=.40) to moderate range (ES = .78); however, significant variance in study effects was found: Response Inhibition ($Q_{w(25)}$=61.41, p < .001, I^2=60.92), Planning($Q_{w(9)}$=15.72, p <.05 ., I^2=49.10), Set Shifting ($Q_{w(22)}$=82.02, p < .001, I^2= 74.40), Verbal Working Memory ($Q_{w(18)}$=54.11, p < .001, I^2= 68.59), Spatial Working Memory ($Q_{w(13)}$=47.32, p < .001, I^2= 74.64), Vigilance ($Q_{w(6)}$=19.96, p < .001, I^2= 74.95).To address the heterogeneity in effect sizes observed among Chinese studies, analyses of potential moderators within the corpus of studies was conducted.

Table 4. Effect Sizes across Executive Function Domains: Chinese Studies

Study	ADHD/TD(n)	Effect Size (g) of the Difference Between Groups across EFs					
		Inhibition	Planning	Set shifting	Verbal WM[a]	Spatial WM[a]	Vigilance
Cao (2011)	32/32	0.96***					
Chan et al. (2006)	22/22			0.19			
Gau et al. (2009)	53/53		0.38	0.02	0.24	0.26	
Gau& Shang (2010)	279/173		0.50***	0.28**	0.48***	0.52***	
Gau& Chiang (2013)	389/317				0.56***	0.58***	
Hang et al.(2010)	52/52			1.21***			
He & Jing (2006)	57/63			0.38*			
He & Jing (2008)	57/63				0.40*		
Jin et al. (2009)	30/18	0.44					0.84**
Jin et al. (2010)	28/18	0.43					
Li et al.(2005)	40/25	0.76**	0.67***	0.86**	0.91	0.87**	
Li (2007)	89/150	0.52***					0.61***
Li (2009)	22/22	1.77***	0.77*				
Lin et al. (2012)	40/40		0.41***	0.21		0.38*	
Li et al. (2008)	124/124			0.60***	0.79***		
Liu & Wang (2004)	72/36	0.71***			0.29		0.73***
Liu & Wang (2002)	55/18	1.16***			0.37		
McAlonan et al. (2009)	22/29	0.62*					
Ou et al. (2012)	59/35			0.48*	0.58**		
Qian et al. (2010)	142/116	0.46***	0.1		0.17		

Study	ADHD/TD(n)	Effect Size (g) of the Difference Between Groups across EFs					
		Inhibition	Planning	Set shifting	Verbal WM[a]	Spatial WM[a]	Vigilance
Shi et al.(2008)	102/102	0.38***					
Shi et al. (2007)	102/102			0.45***			
Shuai et al. (2011)	375/125	0.47***	0.30***	0.51***		0.42***	
Shuai& Wang (2007a)	38/19	0.69**	0.79***	0.82***	0.30	0.68**	
Shuai& Wang (2007b)	44/22	0.59**	0.36	0.84***	0.43*	0.29	
Tu(2010)	30/30	0.38					
Wang(2007a)	31/31	1.25***					
Wang (2009)	31/37	0.19					
Wang (2007b)	70/60			0.56**	0.41*		
Wei(2009)	21/19	0.81***				1.6***	
Wen et al. (2010)	21/22	0.66*		1.50***			
Wu et al. (2012)	37/40			1.49***			
Xiao et al. (2012)	16/16	0.43					0.6
Xu et al. (2011)	39/35				0.73**		
Yang et al. (2008a, 2012a)[b]	100/100	0.51***			0.98***	0.84***	
Yang et al. (2011a)	100/100	0.24			1.04***	0.90***	
Yang et al. (2011b)	91/54	1.02***			0.77***	0.32*	1.4***
Yang et al. (2012b)	142/46	0.89***		0.71***	0.86***	0.77***	
Yang et al. (2008b)	26/30			0.32			
Yao(2007)	90/90			0.46**			
Yao & Li (2003)	45/45			1.38***			
Zhang et al.(2010a, 2010b)[b]	114/76	0.52**		0.12			0.47**

Study	ADHD/TD(n)	Effect Size (g) of the Difference Between Groups across EFs					
		Inhibition	Planning	Set shifting	Verbal WM[a]	Spatial WM[a]	Vigilance
Zhou et al.(2005)	113/83			0.56***			
Weighted mean effect size		0.65[h]***	0.40[h]*	0.59[h]***	0.58[h]***	0.62[h]***	0.78[h]***
±95% confidence interval		0.54,0.75	0.26, 0.54	0.46, 0.72	0.45,0.70	0.48,0.77	0.49, 1.08
Number of studies(%) that found a significant group difference ($p<0.05$)		20/25	6/9	17/22	14/18	11/13	5/6
		80%	67%	77%	78%	85%	83%
Homogeneity Index: p		0.001	0.047	0.001	0.001	0.001	0.001
Homogeneity Index: Q_w		61.41	15.72	82.02	54.11	47.32	19.96

a. Verbal WM, Verbal Working Memory; Spatial WM, Spatial Working Memory; b. Study combined two studies with the same participants during the same period but with published as two studies; c. indicates significant heterogeneity of effect sizes for reasons other than sampling error. *$p<0.05$, **$p<0.1$, ***$p<0.001$

3.2. Moderator Analyses

Overall, the variance in effect sizes found among North American studies was homogeneous, and differed markedly from the heterogeneity in effect sizes found among studies in the Chinese collection. The following analyses examined the influence of key study variables on effect size within each collection of studies including: methodology (sampling method, diagnostic criteria, publication status), participant characteristics (age, IQ), and executive function tasks. With the exception of one category (i.e., sampling method), each subgroup had more than five studies even after the removal of studies because of missing data.

3.2.1. Sampling Method, Diagnostic Criteria, Publication Status

As shown in Table 5, the majority of North American (24/30, 80%) and Chinese (43/43, 100%) studies that reported diagnostic information used DSM-IV criteria to diagnose ADHD among the sample children. No significant variance in effects was attributed to whether or not the study design controlled for medication status of the children or DSM criteria. However, the method used to recruit sample participants accounted for significant variance in effects in North American studies (Q_w = 6.10, p < .05). School based samples (g= .65, SE =.06, CI_{95} = .54, .77) produced larger effects than clinic (g=.48, SE = .06, CI_{95}=.35, .61). Notably, only one study used a combined school/clinic (g=.48, SE = .05, CI_{95} = .39, .57) samples and therefore, this result is treated with caution.

The influence of publication status was evaluated, effect size generated from Chinese dissertations (g=.82, SE =.12, CI_{95}=.57, 1.06) was larger than the average effect size from published Chinese journal articles (g=.58, SE =.04, CI_{95}=.50, .66), however the difference failed to reach statistical significance (Qw=3.37, *p*=0.07). The difference between effect sizes generated by North American dissertations (g=.55, SE =.07, CI_{95}= .42, .69), and published North American journal articles (g=.53, SE =.04, CI_{95}=.46, .60; Qw=0.08) was also not statistically detectible.

Table 5. ***Study Methodology Analyses***

Moderator	Chinese				North American				CH vs. NA Qb
	k	G	95%CI	Qw(p)	K	G	95%CI	Qw (p)	
Sampling method									
Clinic	34	0.61	0.52,0.70		8	0.48	0.35,0.61		2.46
School	8	0.67	0.46,0.88	0.61 (0.74)	5	0.65	0.54,0.77	6.10[e]* (0.04)	0.02
Combined	1	0.57	0.42,0.72		17	0.48	0.39,0.57		1.00
Diagnosed criteria									
DSM-III-R					1	0.49[b]	0.31,0.68		
DSM-IV	43	0.61	0.54,0.69	0 (1)	24	0.53	0.46,0.6	0.39 (0.82)	2.34
DSM-IV-TR					5	0.58	0.37,0.79		
Medication Control									
Yes	36	0.62	0.53,0.70		25	0.53	0.46,0.6		2.53
No				0.1 (0.75)	1	0.49[b]	0.31,0.68	0.67 (0.72)	
No information	7	0.57	0.3,0.84		4	0.62	0.37,0.88		0.07
Publication status									
Published	35	0.58	0.50,0.66	3.34 (0.07)	18	0.53	0.46,0.60	0.08 (0.78)	0.69
Dissertation	8	0.82	0.57,1.06		12	0.55	0.42,0.69		3.42

a. k=the number of studies; b. ES obtained from one study; c. Qb refers to differences across North American and Chinese subgroups (df = 1); d. Qw refers to moderator contrasts (df= number of subgroups -1); e. indicates significant heterogeneity of effect sizes for reasons other than sampling error. *p<0.5, **p<0.01, ***p<0.001.

3.3. Measures of Executive Functions

One possible moderator of variance in effect sizes is the executive function task. To date, few studies have explicitly investigated whether the components that underlie performance on different measures of executive function are culturally invariant between North American and Chinese samples(e.g., WCST: He & Jing, 2006; Mullane & Corkum, 2007; Shi et al., 2007; Stroop task: Hummer et al., 2011; Shi, Wu, Wang, & Sun, 2008). With this limitation in mind, the following analyses investigate effect size variance associated with specific executive function measures for North American and Chinese studies separately. Analyses were conducted on measures that tapped the four domains of executive functions that approximately 50% of North American studies and Chinese studies found discriminated children with and without ADHD: Response Inhibition, Set Shifting, Working Memory and Vigilance. Measures that tapped Planning and Complex

Executive Functions are not included in the present analysis due to the small number of studies in both North American and Chinese corpuses that found significant effects on these constructs. However, a full description of measures used in North American and Chinese studies to tap Planning and Complex Executive Functions are shown in Appendix C and D.

In total, 19 measures from 6 executive function domains were identified for inclusion in the meta-analyses. Complex tasks that reportedly tapped several executive function domains were used in some North American studies; whereas Chinese studies used only measures that reportedly tapped a single executive function construct.

The majority of North American studies (22/30, 73%) used computerized measures of executive functions whereas almost half of Chinese studies (20/43, 47%) utilized computerized measures. Within the corpus of Chinese studies, the heterogeneity in effect sizes obtained from computerized (g=0.67, SE=0.08, CI_{95} = 0.51, 0.84, Q_w= 77.85, $p<0.001$) and non-computerized (g=0.61, SE=0.05, CI_{95}=0.52, 0.71, Q_w= 86.89, $p<0.001$, I^2=65.47) executive function measures was significant; however differences in mean effect sizes between computerized/non-computerized executive function tasks was not statistically detectible (Q_b=0.35, p=0.55>0.05). In North American studies, the variation in effect sizes within computerized (g=0.51, SE=0.04, CI_{95} = 0.44, 0.59, Q_w= 23.68, $p>0.05$) and non-computerized (g=0.51, SE=0.04, CI_{95}=0.43, 0.59, Q_w= 32.36, $p>0.05$) was not statistically significant, and computerized/non-computerized task differences in effects was also not statistically detectible (Q_b=0.0003, p=0.99). Also, no significant differences were detectible between mean effect sizes obtained from computerized (Q_b=2.94, $p > 0.05$) or non-computerized (Q_b=2.64, $p > 0.05$) executive function tasks across North American and Chinese studies. The high degree of homogeneity of variance in effects obtained on both computerized and non-computerized executive function tasks within the North American studies compared to the heterogeneity in effect sizes obtained in the Chinese studies suggests that even though the mean effect sizes are statistically comparable, computerized and non-computerized executive function tasks may be tapping culturally different constructs in the two corpuses of studies.

3.3.1. Response Inhibition

Significant effect size estimates of the difference between children with and without ADHD in their performance on measures of Response Inhibition were found in 19 of 25 (76%) North American studies and 24 of 32 (78%) Chinese studies. The most frequently used measure of Response Inhibition was the Continuous Performance Task (CPT) in North American studies and the Stroop Colour Word Test (SCWT) in Chinese studies; however, effect sizes on these measures within each sample of studies was highly variable and ranged from g=.28 to .58 for the CPT in North American studies and g=.30 to .65 for the SCWT in Chinese studies. In both Chinese and North American studies, ADHD/control group performance differences on the Go-No-Go task were highly variable. In contrast, Chinese and North American studies that used the Stop Signal Reaction Time (SSRT) measure consistently reported moderate effect sizes (i.e., on 9/10 studies) that were statistically detectible. Variability in effects calculated from the SSRT was not significant in either North American (Q_t= 5.34, p = .38, I^2 = 6.37) or Chinese study samples (Q_t= 3.53, p = .32, I^2 = 14.91).

Table 6. Mean Effect Sizes on Measures of Response Inhibition in North American and Chinese Studies

	North American					Chinese			
	CPT[a]	**SSRT[b]**	**SCWT[c]**	**D-KEFS DCWI3[c]**	**Go/No-Go[d]**	**CPT[a]**	**SSRT[b]**	**SCWT[c]**	**Go/No-Go[d]**
Weighted mean effect size	0.43[h]***	0.63***	0.62***	0.61***	0.54[h]**	1.77[e]***	0.47***	0.59[h]***	0.74[h]*
±95% confidence interval	0.28, 0.58	0.52,0.74	0.49, 0.75	0.39,0.83	0.15, 0.92	1.08,2.45	0.3,0.65	0.50,0.69	0.11,1.36
Number of studies that found a significant group difference (p<0.05)	4/10	6/6	5/6	6/7	3/4	1/1	3/4	17/21	3/6
%	40%	100%	83%	86%	75%	100%	75%	81%	50%
Homogeneity Index: *p*	0.04	0.38	0.1	0.07	0.01	1	0.32	0.01	0.001
Homogeneity Index: Q_t	17.38	5.34	18.53	11.83	10.71	0	3.53	39.64	78.01

a.CPT = Continuous Performance Task, commission error and reaction time; b. SSRT = Stop Signal Reaction Time; c. Stroop Colour Word test paradigms including classic Stroop Colour Word Task(SCWT) and Stroop Colour Word Task in D-KEFS (D-KEFS DCWI3); d. Go/ No-Go task commission errors or percentage of commission errors; e. ES was obtained from one study; f. indicates significant heterogeneity of effect sizes for reasons other than sampling error. **p*<0.5, ***p*<0.01, ****p*<0.001.

3.3.2. Set Shifting

The most commonly used measure of set shifting in both North American and Chinese studies was the Wisconsin Card Sorting Task (WCST; 42% of North American studies and 58% of Chinese studies). Whereas the mean effect size on this measure was significant in 50% of North American studies (g=.44, CI_{95}=. 34, .53, Q_t=2.11, *p*<0.95), the majority of Chinese studies (10 of 13 studies, 77%) that used the WCST reported a range from moderate to large effects (g=.66, CI_{95}=.45, .87, Q_t=56.71, *p*<0.001). A greater proportion of significant effects were found in both North American (83%) and Chinese (100%) studies that utilized the Trial Making Test (TMT) of Set Shifting.

Table 7. Mean Effect Sizes on Measures of Set Shifting in North American and Chinese Studies

	North American				Chinese		
	TMT[a]	**DTMC4[a]**	**WCST[a]**	**CANTAB ID/ED[a]**	**TMT[a]**	**WCST[a]**	**CANTAB ID/ED[a]**
Weighted mean effect size	0.55[c]***	0.42***	0.44***	0.31[b]	0.59***	0.66[c]***	0.22**
±95% confidence interval	0.36, 0.74	0.18,0.59	0.34,0.53	-0.23, 0.86	0.49,0.70	0.45,0.87	0.8,0.37
Number of studies that found a significant group difference (p<0.05)	5/6	2/4	4/8	1/1	7/7	10/13	1/3
%	83%	50%	50%	100%	100%	77%	33%
Homogeneity Index: p	0.02	0.21	0.95	1	0.4	0.001	0.48
Homogeneity Index: Q_t	13.9	4.55	2.11	0	6.17	56.71	1.46

a. TMT= Trail Making Test; WCST = Wisconsin Card Sorting Test; CANTAB ID/ED = Intra-Extra Dimensional Set Shift of CANTAB; b. ES obtained from one study; c. indicates significant heterogeneity of effect sizes for reasons other than sampling error. *p<0.5, **p<0.01, ***p<0.001.

Table 8. Mean Effect Sizes on Measures of Working Memory in North American and Chinese studies

	North American						Chinese					
	Verbal working Memory				Spatial Working Memory		Verbal Working Memory	Spatial Working Memory				
	DS	**DSBW**	**SeST**	**CST**	**SWM**	**SSP**	**DSBW**	**SST**	**SWM**	**SSP**	**CBT**	**ROCF**
Weighted mean effect size	0.61***	0.53c***	0.49c***	0.65***	0.61***	0.41**	0.58c***	1.19***	0.54***	0.39***	0.92c***	0.53**
±95% confidence interval	0.48,0.73	0.22,0.85	0.24,0.74	0.52,0.77	0.50, 0.72	0.16, 0.67	0.45,0.7	0.6,1.78	0.43,0.65	0.24,0.55	0.44,1.4	0.32,0.75
Number of studies that found a significant group difference (p<0.05)	5/6	2/3	2/3	2/2	4/6	2/2	13/18	2/2	3/4	2/3	4/4	3/4
%	83%	67%	66%	100%	67%	100%	72%	100%	75%	67%	100%	75%
Homogeneity Index: *p*	0.51	0.01	0.04	0.7	0.60	0.50	0.001	0.08	0.36	0.34	0.001	0.08
Homogeneity Index: Q_t	4.31	8.43	6.3	0.15	3.67	0	54.11	3.10	3.2	2.14	26.84	6.78

a. DSBW= Digit Span Backwards; SeST= Sentence Span Task; CST= Counting Span Test; SST= Spatial Span paradigm; SWM= Spatial Working Memory subtest of CANTAB; SSP= Spatial Span subtest of CANTAB; CBT= Corsi Blocks Test; ROCF= Rey-Osterrieth Complex Figure Immediate and Delay recall condition; **b**. ES was obtained from one study; **c**. indicates significant heterogeneity of effect sizes for reasons other than sampling error. *p<0.5, **p<0.01, ***p<0.001.

3.3.3. Working Memory

Whereas a broad range of measures of working memory were used in North American studies, the Digit Backwards Span task (DSBW) from the C-WISC was predominantly used in Chinese studies. Due to the small number of studies in the North American sample that used individual measures for assessing working memory, interactions between the influence of the executive function measure and variance in effects could not be reliably determined. Notably, the pattern of effect sizes observed on the Digits Backwards measure for Chinese studies was heterogeneous (Q_t = 54.11, CI_{95} =.45, .70, p < .001, I^2= 68.59) and ranged from g=0.17-1.04.

3.3.4. Vigilance

The measure most frequently used in North American studies to assess Vigilance in children was the CPT: errors of omission. The range of effects fell in the moderate range on this measure (g=.52-.71) and the heterogeneity in effects was not statistically significant (Q_t= 7.16, p= .52, I^2=0.00). The number of North American and Chinese studies that utilized other common measures of vigilance was not sufficient (i.e., < 4 studies) to conduct moderator analyses.

Table 9. Mean Effect Sizes on Measures of Vigilance in North American and Chinese Studies

	North American		Chinese		
	CPT	**Go/No-Go**	**CPT**	**Go/No-Go**	**NCT**
Weighted mean effect size	0.61***	1.08[b]***	0.47[b]**	1.01[c]***	0.66***
±95% confidence interval	0.52,0.71	0.55,1.62	0.18,0.77	0.52,1.51	0.45,0.87
Number of studies that found a significant group difference (p<0.05)	9/9	1/1	1/1	2/3	2/2
%	100%	100%	100%	67%	100%
Homogeneity Index: p	0.52	1	1	0.05	0.61
Homogeneity Index: Q_t	7.16	0	0	6.18	0.26

a. omission errors (number or percentage) of CPT= Continuous Performance Task; omission error of Go/No-Go Task; NCT= Number Cancellation Test; **b.** data obtained from one study. **c**. indicates significant heterogeneity of effect sizes for reasons other than sampling error. *p<0.5, **p<0.01, ***p<0.001.

3.4. Child Characteristics

3.4.1. ADHD Subtypes and Co-morbid Disorders

As shown in Table 10, the majority of studies in both Chinese and North American collections did not identify ADHD subtypes or co-morbid disorders in their samples. The smallest mean effect size was reported for the ADHD-Hyperactive Inattentive subtype (ES = .37) among the Chinese studies; however, this result was generated from only 6 studies.

Table 10. ADHD Subtypes and Comorbid Disorders

Subgroups	Chinese				North American				Q between
	k[c]	g	95% of CI	$Q_w(p)$	k[c]	g	95% of CI	$Q_w(p)$	CH VS.NA
Subtypes									
ADHD mix[a]	36	0.61	0.52,0.71		20	0.50	0.42,0.57		3.38
ADHD-C	10	0.68	0.56,0.80		8	0.63	0.34, 0.92		0.10
ADHD-HI	6	0.37	0.16,0.57	7.76(0.05)	1	0.46[d]	-0.13, 1.04	0.6(0.9)	0.08
ADHD-I	10	0.51	0.36,0.67		7	0.51	0.29, 0.73		0.001
Comorbidity									
ADHD+ODD[e]	2	0.36	0.06,0.66		1	0.55[d]	0.03,1.08		0.39
ADHD+DBD[e]	1	0.64[d]	0.00,1.28		1	0.42[d]	-0.13, 0.97		0.26
ADHD+LD[e]	1	0.61[d]	0.01,1.21	1.18(0.76)				1.96(0.38)	
ADHD+TD[e]	1	0.33[d]	-0.11,0.76						
ADHD+RD[e]					1	0.83[d]	0.53,1.13		

a. ADHD without identified subtypes; b. ADHD-C=Combined type; ADHD-HI= Hyperactive/Impulsive type; ADHD-I= Inattentive type; c. the number of groups with this subtype; d. data of subgroups were from one study; e. ADHD+ODD=Oppositional defiant disorder; ADHD+DBD= Disruptive behavior disorder; ADHD+LD= Learning disability; ADHD+TD= Tic disorder; ADHD+RD= Reading disability.

3.4.2. Age and IQ

To investigate the influence of age and IQ on the association between ADHD and executive function domains, meta-regression analyses were conducted with effects on each domain of executive functions in Chinese studies as the dependent variables. Regression analyses were conducted for North American studies only for Response Inhibition, due to the lack of heterogeneity in effect sizes previously observed for the other domain. The contribution of age to variance in effects for Set Shifting, Vigilance, and Overall executive functions and the influence of IQ on variance in effects on Verbal Working Memory and Vigilance were significant ($p<.05$). The negative beta weights (slope) obtained in each instance suggests a proportionate decrease in weighted mean effects was found as age and IQ increased. However, the practical significance of this finding is somewhat limited, given the very small absolute value of each coefficient and the magnitude of change observed.

Table 11. The Influence of Age on Effect Size

Study	Point estimate	Standard error	Lower limit	Upper limit	Z-value	p-Value
Chinese						
Response Inhibition						
Slope	-0.0016	0.0045	-0.0101	0.0072	-0.3654	0.7148
Intercept	0.8296	0.5004	-0.1511	1.8103	1.6581	0.0973
Planning						
Slope	0.0050	0.0039	-0.0026	0.0125	1.2820	0.1998
Intercept	-0.2477	0.4992	-1.2261	0.7307	-0.4962	0.6197
Set shifting						
Slope	-0.0103	0.0036	-0.0174	-0.0033	-2.8910	0.0038
Intercept	1.8323	0.4369	0.9759	2.6887	4.1935	0.0001
Verbal working memory						
Slope	-0.0064	0.0036	-0.0135	0.0007	-1.7765	0.0757
Intercept	1.3444	0.4335	0.4946	2.1941	3.1009	0.0019
Spatial working memory						
Slope	-0.0062	0.0040	-0.0139	0.0016	-1.5649	0.1176
Intercept	1.3861	0.4926	0.4206	2.3517	2.8137	0.0049
Vigilance						

Study	Point estimate	Standard error	Lower limit	Upper limit	Z-value	p-Value
Slope	-0.0135	0.0060	-0.0253	-0.0017	-2.2343	0.0255
Intercept	2.3507	0.7109	0.9574	3.7440	3.3067	0.0009
Overall						
Slope	-0.0052	0.0025	-0.0102	-0.0002	-2.0537	0.0400
Intercept	1.2225	0.2961	0.6421	1.8029	4.1284	0.0000
North American						
Response Inhibition						
Slope	0.0023	0.0019	-0.0015	0.0061	1.1779	0.2388
Intercept	0.2503	0.2532	-0.2459	0.7466	0.9887	0.3228

Table 12. The Influence of IQ on Effect Size

Study	Point estimate	Standard error	Lower limit	Upper limit	Z-value	p-Value
Chinese						
Response Inhibition						
Slope	0.0055	0.0144	-0.0226	0.0336	0.3828	0.7018
Intercept	0.0735	1.4996	-2.8657	3.0127	0.0490	0.9609
Planning						
Slope	0.0016	0.0258	-0.0489	0.0520	0.0601	0.9521
Intercept	0.2399	2.7560	-5.1618	5.6416	0.0870	0.9306
Set shifting						
Slope	-0.0585	0.0472	-0.1510	0.0339	-1.2406	0.2148
Intercept	6.7500	4.9620	-2.9754	16.4753	1.3603	0.1737
Verbal working memory						
Slope	-0.0470	0.0172	-0.0807	-0.0133	-2.7327	0.0063
Intercept	5.4316	1.7753	1.9521	8.9110	3.0596	0.0022
Spatial working memory						
Slope	-0.0168	0.0204	-0.0567	0.0232	-0.8240	0.4100
Intercept	2.3683	2.1181	-1.7831	6.5197	1.1181	0.2635
Vigilance						
Slope	-0.1025	0.0249	-0.1512	-0.0538	-4.1234	0.0000
Intercept	11.2468	2.5425	6.2635	16.2300	4.4235	0.0000
Overall						

Study	Point estimate	Standard error	Lower limit	Upper limit	Z-value	p-Value
Slope	-0.0190	0.0127	-0.0438	0.0058	-1.5020	0.1331
Intercept	2.6038	1.3240	0.0089	5.1987	1.9667	0.0492
North American						
Response Inhibition						
Slope	0.0049	0.0097	-0.0141	0.0240	0.5086	0.6110
Intercept	0.0237	1.0245	-1.9842	2.0317	0.0232	0.9815

3.5. Research Questions

The results of this synthesis produced five important findings. First, the magnitude of performance differences between Chinese and North American samples of children with and without ADHD, on average, fell in the moderate range on all executive function constructs. Second, average performance differences between ADHD and non-ADHD children on measures of executive functions that were observed in North American and Chinese studies were not statistically detectible. That is, the pattern of differences between children with ADHD and their non-ADHD peers in performance on executive function measures found in North American samples is consistent with the distribution of mean effects in Chinese samples. Third, in both North American and Chinese studies, children with ADHD consistently performed less well than their peers without ADHD on measures that tapped Response Inhibition, Working Memory, and Vigilance. Fourth, although differences between North American and Chinese studies in effects for each construct of executive functions were not statistically detectible, heterogeneity of effects was statistically detectible within Chinese studies. Lastly, North American studies that drew samples of children with ADHD from clinics typically found that estimates of differences in executive functions between children with and without ADHD were more conservative than those found in studies that relied upon samples from school-based populations. In addition, as the age and IQ of Chinese study samples increased, the average magnitude of differences between children with and without ADHD decreased.

In summary, the meta-analyses described in this research were conducted to compare the contribution of executive functions to ADHD symptomology among children living in North America and among children living in Asia. Findings from both reviews suggest that in a number of domains, executive functions play a significant role in differentiating the behavior of children with and without ADHD. These findings affirm and extend those initially reported by Alderson et al., (2007), Frazier et al., (2004), Homack & Riccio (2004), Lijffijt et al., (2005), Martinussen et al., (2005), Pauli-Pott & Becker (2011), Pennington & Ozonoff (1996), Romine et al., (2004) and Willcutt et al., (2005). A focused discussion of these findings with reference to the research questions posed is presented in the remainder of this section.

a. What is the magnitude of performance differences between children with and without ADHD on measures of inhibition, planning, set shifting, working memory, and vigilance among Chinese studies and North American studies?

The magnitude of the average effect size observed on each category of executive functions consistently fell in the moderate range in meta-analyses of both Chinese and North American studies (Chinese: mean ES = 0.40-0.78; North American: mean ES = 0.45-0.64). On average, children identified with ADHD performed worse than age peers without ADHD on measures of executive functions in all domains. Among the North American studies, the magnitude of effect sizes appeared to be stronger on measures of inhibition, working memory and vigilance; however, these differences did not reach statistical significance.

b. Is the pattern of effect sizes observed within Chinese studies comparable to that found within North American studies?

While average effect sizes were moderate in Chinese and North American studies, the range of effect sizes generated within each domain of executive functions varied significantly between North American and Chinese studies. With the exception of response inhibition, effect size estimates were highly homogeneous in North America studies; however the distribution of effect sizes within Chinese studies were highly heterogeneous. Specifically, unexplained variation in effect sizes in the Chinese studies was significant within the categories of response inhibition, set shifting, verbal and spatial working memory, vigilance and overall executive functions.

It is noteworthy that particular measures of executive functions generated more consistent effects in both North American and Chinese studies. For instance, the Stop Signal task reliably tapped performance differences between children with and without ADHD in both corpuses of studies, a finding that is consistent with results of previous meta-analyses (Frazier et al., 2004; Willcutt et al., 2005). In contrast, effect sizes generated using the Stroop colour word paradigm in North American studies were highly homogeneous compared to the heterogeneity in effects observed in Chinese studies. In North American studies, children with ADHD consistently exhibited poorer performance than control children on the Stroop colour word measure (average ES = .62). This finding appears to be consistent with Homack and Ricco's (2004) observation that Stroop colour word tasks have a high degree of sensitivity and specificity when used with North American samples of children with ADHD. However, the high degree of variability in effects observed in the Chinese studies suggests that component processes involved with the Stroop effect maybe language-specific. For instance, the orthography that represents the words in a specific writing system may lead to a qualitatively and quantitatively different Stroop effect (Biederman & Tsao, 1979; Chen & Juola, 1982) reported that a Stroop effect was greater in Chinese for Chinese-speaking participants than in English for English-speaking participants.

c. Is variation in effect sizes moderated by sample characteristics (i.e., age, IQ, diagnostic criteria), study characteristics (sample selection, DSM criteria, publication status) or the executive function task?

While the magnitude of effect size did not vary as a result of the diagnostic criteria used to identify samples of children with ADHD in Chinese samples, the possibility exists that perceptions of ADHD may vary among clinicians in Mainland China, Hong Kong (Alban- Metcalfe, Cheng-Lai, and Ma, 2002; Norvilitis & Fang, 2005) and Taiwan. Moreover, with increases in age of participants in study samples, ADHD/non-ADHD group differences in performance on measures of set shifting, vigilance and overall executive functions decreased. IQ also appears to be a significant moderator of variation in effect sizes within verbal working memory and vigilance domains. As Chinese sample IQ's increased, the magnitude of effect size estimates decreased. This finding is consistent with research reported by Mahone et al. (2002) where IQ was found to be more important to the explanation of ADHD/non-ADHD group differences when IQs are in the average than in the above-average range.

No differences in effects were found between unpublished dissertations and journal publications in either the corpus of North American or Chinese studies. However, the absence of data to fully evaluate study quality within Chinese studies is worth mentioning for this factor may have also contributed to the high degree of heterogeneity in effect sizes. For instance, children with ADHD who had a history of being treated with stimulant medication were excluded from the majority of Chinese samples. Socioeconomic status (SES) of the family, or parents' education levels were reported only in 3 Chinese studies conducted by the same research group in Taiwan (Gau et al., 2009; Gau & Shang, 2010; Gau & Chiang, 2013). According to Ardila et al. (2005), parent education level is associated with children's performance on executive function measures and this variable was not reported in any of the Chinese studies.

In summary, the findings of this research support the idea that executive functions are an important component of ADHD symptomology across cultures; however, there are also indications that performance on executive function tasks may be culture specific. More research is needed to clarify whether executive function tasks are culturally invariant across Chinese and North American samples.

4. Study Limitations and Implications for Future Research

Unfortunately, due to the limited information provided in Chinese studies regarding socioeconomic status and gender, the influence of these factors on effect size estimates could not be analysed in this meta-analysis. Caution must also be exercised when comparing performance of different cultural groups on measures that have not been evaluated for cultural invariance (Ardila, 2005; Hedden, Park, Nisbett, Ji, Jing, & Jiao, 2002; Nell, 2000; Rosselli, & Ardila, 2003).

The studies in this meta-analysis were limited to those with English or Chinese speaking samples. Studies of children with ADHD living in Europe or other areas of the world were not included in these analyses. Further investigation of other cultural groups is necessary to affirm the findings of this review in a global context. Furthermore, the Chinese studies were conducted in several different countries in Asia, and there was insufficient data available to determine whether some of the heterogeneity in effect sizes for this corpus was due to within-group cultural variation.

4.1. Implications for the Future Research

According to the findings in this meta-analytic review, it is essential to conduct further research on the cultural invariance of executive function tasks. Chinese studies that are more carefully controlled for variance in effects due to socio-economic status, IQ, and age are sorely needed in order to make reliable comparisons with findings from North American studies.

Furthermore, since diagnostic criteria for ADHD in the recently published DSM-V (Diagnostic and Statistical Manual of Mental Disorders fifth edition, 2013) has changed in that ADHD can now be diagnosed in addition to autistic spectrum disorders. Future studies will need to assess whether executive functions in children diagnosed with

ADHD in addition to Autism Spectrum disorder are the same or different from children diagnosed with either disorder in isolation.

Finally, as the studies of executive functions in adults with ADHD are accumulating, studies that include samples of children and young adults together are necessary to learn more about the developmental trajectory of executive functions and symptomology associated with ADHD.

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Appendix A. Demographic Information of North American (k=30) and Chinese (k=43) Studies

Study	DSM Criteria	ADHD/ TD(n)	Avg. Age(m)	Age (yrs)	Avg.FIQ[b]	Sample Method[c]	Medica -tion Control	Public -ation	EF Measures[f]
Alford (2006)	DSM-IV	30/30	124.27±23.8	7-14	100.4±17.69	Combined	Y	D	CCPT-II, D-KEFS:CWIT
Babb et al. (2010)	DSM-IV	22/58	117	7-11	NI	Combined	Y	P	WCST-64
Bidwell et al. (2007)	DSM-IV	332/266	134.11±31.6	8-18	101.8±12.7	School	Y	P	CPT, SSRT,SCWT,WCST, TMT, WISC-R DS, CANTAB:SWM
Biederman et al. (2004)	DSM-III-R	173/196	157.5±42	6-17	109.2±11.9	Clinic	N	P	ROCFT, Auditory CPT, WCST, SCWT
Cantrill (2003)	DSM-IV	28/28	111.18±13.20	8-11	109.4±11.58	School	Y	D	CPT,SCWT
Closson (2010)	DSM-IV-TR	25/ 25	188.11±33.17	10-18	NI	Clinic	Y	D	WCST, TOL
Huang-Pollock et al. (2009)	DSM-IV	56/36	114.83±16.56	8-12	106.17±13.57	Clinic	Y	P	SSRT, DS, ROCFT
Edmonds (2007)	DSM-IV	29/15	171.18±21.21	12-17	111.17±14.14	Combined	Y	D	Gordon Diagnostic system, D-KEFS:VF,Tower
Garaas (2007)	DSM-IV	27/ 30	115.13±23.22	7-12	91.85	Clinic	Y	D	DS, TMT, CCPT, RCFT
Goldberg et al. (2005)	DSM-IV	21/32	117.18±15.18	8-12	113.8±10.3	Clinic	Y	P	SCWT, CANTAB
Hale et al. (2009)	DSM-IV	64/42	109.55±21.89	6-12	95.14±8.74	School	Y	P	TMT Part B
Hummer et al. (2011)	DSM-IV	25/25	176.11±14.11	13-17	80-120	Combined	NI	P	SCWT, CCPT, WMS
Karalunas & Huang-Pollock (2011)	DSM-IV-TR	45/46	121.38.±17.0 7	8-12	106.80±10.79	Combined	Y	P	SSRT
Loftis (2004)	DSM-IV	37/39	145.20±25.27	8-16	108.64±13.27	Combined	Y	D	WISC-III Spatial Span, D-KEFS, GO/No Go, SOP

Study	DSM Criteria	ADHD/ TD(n)	Avg. Age(m)	Age (yrs)	Avg.FIQ[b]	Sample Method[c]	Medica -tion Control	Public -ation	EF Measures[f]
Mahone et al. (2005)	DSM-IV	40/40	60±9.7	3-6.5	NI	Combined	Y	P	Go/No GO task, Auditory CPT-P, Multiple Boxes Task
Martel (2009)	DSM-IV	168/ 144	152.15±36.3	8-17	103.09±12.66	Combined	Y	D	SSRT, TMT
Miller et al. (2012b)	DSM-IV	137/86	115	6-12	99.65±13.6	Combined	Y	P	CCPT, ROCF,WISC-III DSBW
Mullane & Corkum (2007)	DSM-IV-TR	15/15	100±14.16	6-11	98.6±11.56	Clinic	NI	P	WCST, SSRT,
Naidoo (2007)	DSM-IV	34/17	139.9±21.21	9-14.92	108.83±9.3	School	NI	D	WISC-IV WMI
O'Brien et al. (2010)	DSM-IV	56/90	122.11±15.18	8-13	108.30±12.8	Combined	Y	P	Go/No-Go, WISC-IV(DSBW), CANTAB: SWM, WISC-III Spatial Span BW, D-KEFS
O'Donnell (2004)	DSM-IV	56/31	137.26±26.15	8-16	NI	Clinic	Y	D	WISC-III DSBW, DSFW, CCPT
Peden (2010)	DSM-IV	32/ 37	129.18±23.19	8-14	99.1±15.8	Combined	Y	D	CCPT-II, D-KEFS
Schuster (2005)	DSM-IV	30/ 29	135.18±20.4	9-14	NI	Clinic	Y	D	WISC-III DSFW, WCST, TMT
Semrud-Clikeman et al. (2008)	DSM-IV	39/39	145.13±22.27	9-15	NI	Combined	Y	P	TOL, SCWT
Semrud-Clikeman et al. (2010)	DSM-IV	49/32	124.2±22.13	9.6-16.5	109.17±11.2	Combined	Y	P	D-KEFS
Walkowiak (2008)	DSM-IV-TR	40/20	134±26.64	8-15	116±13.4	Combined	Y	D	D-KEFS
Willcutt et al. (2005b)	DSM-IV	113/151	133.27±31.16	8-18	100±12.74	School	Y	P	SSRT, CPT, WCST, TMT, WISC-R DS subtest, CANTAB:SWM, SCWT,Sentence span task, CST
Wodka et al. (2007)	DSM-IV	43/72	139.5±25.6	NI	109±13.2	Combined	Y	P	Go/No-Go
Wodka et al. (2008a,2008b)	DSM-IV	54/69	141.18±26.12	8-16	109±13.7	Combined	Y	P	D-KEFS

Study	DSM Criteria	ADHD/ TD(n)	Avg. Age(m)	Age (yrs)	Avg.FIQ[b]	Sample Method[c]	Medica -tion Control	Public -ation	EF Measures[f]
Youngwirth et al. (2007)	DSM-IV	28/123	56.58±3.68	4-5.6	NI	Combined	NI	P	K-CPT
Chinese									
Cao (2011)	DSM-IV	32/32	100.27±6	8.41±0.5	IQ>80	Clinic	Y	D	C-WISC, Simon Stroop
Chan et al. (2006)	DSM-IV	22/22	100.2	NI	106.08±19.46	Clinic	NI	P	SART, VF, Stroop test, WCST-modified by Nelson(1976)
Gau et al. (2009)	DSM-IV	53/53	152.11	11-16	107.3±10.6	Clinic	Y	P	CANTAB:IED,SOC, SSP, SWM, DS
Gau & Chiang (2013)	DSM-IV	389/317	144.7	8-17	IQ>80	Combined	Y	P	WISC-DS, CANTAB:SWM,
Gau & Shang (2010)	DSM-IV	279/173	150	12.5±1.6	103±11.6	Clinic	Y	P	CANTAB:ID/ED,SOC, SSP, SWM); DS
Hang et al. (2010)	DSM-IV	52/52	98.11±24	5.5-12	97.13 ±24.15[c]	School	Y	P	WCST-128
He & Jing (2006)	DSM-IV	57/63	111.21±21.25	6-13	NI	Clinic	Y	P	WCST-128
He & Jing (2008)	DSM-IV	57/63	108±24	6-13	103.2±14.7	Clinic	Y	P	WMS
Jin et al. (2009)	DSM-IV	30/18	102±17.1	6-11	85.07±8.45[c]	Clinic	Y	P	Go/No-Go
Jin et al. (2010)	DSM-IV	28/18	NI	6-11	50%-95%[c]	Clinic	Y	P	Go/NoGO
Li (2009)	DSM-IV	22/22	114.23±16.05	7-12	116.27±13.1	Clinic	Y	D	C-WISC, CPT, TOL
Li et al. (2005)	DSM-IV	40/25	110.11±16.23	7.5-12	NI	Clinic	Y	P	C-WISC, SCWT, Go/No-Go, TOL, TMT
Li et al. (2008)	DSM-IV	124/124	124.24±31.6	10.4	NI	Clinic	Y	P	SCWT, VF, WCST-128[d], DSBW
Li (2007)	DSM-IV	89/150	112.24±12	8-11	NI	School	Y	D	SCWT, NCT
Lin et al. (2012)	DSM-IV	40/40	141	8-16	107.43±11.6	Clinic	Y	P	CANTAB:RT, ,SOC, SSP, SWM, ID/ED
Liu & Wang (2002)	DSM-IV	55/18	108.±24	7-13	100±14.230	Clinic	Y	P	C-WISC: DSBW,SCWT

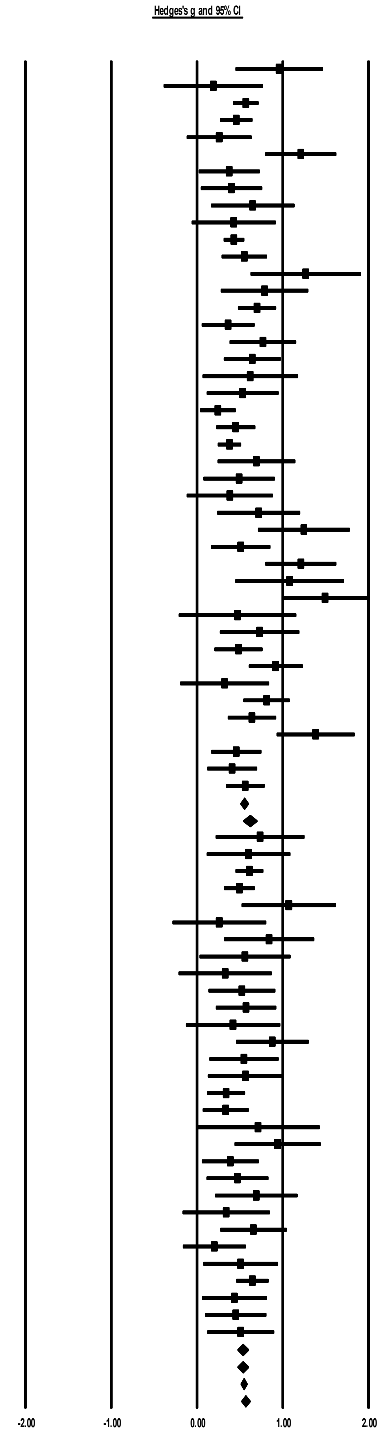
Study	DSM Criteria	ADHD/ TD(n)	Avg. Age(m)	Age (yrs)	Avg.FIQ[b]	Sample Method[c]	Medica -tion Control	Public -ation	EF Measures[f]
Liu & Wang (2004)	DSM-IV	72/36	116.11±24	NI	99.17±15.15	Clinic	NI	P	C-WISC, WMS, Raven, NCT, SCWT
McAlonan et al. (2009)	DSM-IV	22/29	106.13	6-12	114.09±18.14	Clinic	Y	P	SSRT
Ou et al. (2012)	DSM-IV	59/35	110.5±22.23	7-13	MMSE≥20	Clinic	NI	P	C-WISC, TMT, DSFW/BW
Qian et al. (2010)	DSM-IV	142/116	108.84±23.04	7-13	108.24±13.66	Clinic	Y	P	C-WISC, SCWT, TMT, DS, ToH
Shi et al. (2008)	DSM-IV	102/102	104.11±18	6-12	106.9±14[c]	School	Y	P	SCWT
Shi et al. (2007)	DSM-IV	102/102	96±18	6-12	106.9±14[c]	School	Y	P	WCST-128
Shuai & Wang (2007a)	DSM-IV	38/19	132.10±25.23	7-14	104.84±14.85	Clinic	Y	P	C-WISC, SCWT, RCFT,DS, TMT, TOH, VFT
Shuai & Wang (2007b)	DSM-IV	44/22	124.13±21.28	6-13	106.18±15.60	Clinic	Y	P	C-WISC, SCWT, RCFT,TMT, TOH,VF
Shuai et al. (2011)	DSM-IV	375/125	119.22±24.25	6-15	108.68+11.54	Clinic	Y	P	SCWT, RCFT, TMT, TOL, VF
Tu (2010)	DSM-IV	30/30	107.15±15.25	7-12	66.03±12.0[c]	School	NI	D	SCWT
Wang (2009)	DSM-IV	31/37	99.25±11.1	7-9	≥85	Clinic	Y	D	Simon-Stroop
Wang (2007a)	DSM-IV	31/31	101.22±9.55	7-9	NI	Clinic	Y	D	SCWT
Wang (2007b)	DSM-IV	70/60	115.20±22.9	6-14	MMSE≥20	Clinic	Y	D	WCST-128[d],TMT, WMS
Wei (2009)	DSM-IV	21/19	NI	7-12	MMSE≥20	School	Y	D	Sms, CorisBlock, Stroop, Go/No-Go
Wen et al. (2010)	DSM-IV	21/22	NI	7-8	NI	School	Y	P	SCWT, WCST-64[d]
Wu et al. (2012)	DSM-IV	37/40	104	7-12	IQ>70	Clinic	Y	P	C-WISC, DSFW/BW, WCST-128
Xiao et al. (2012)	DSM-IV	16/16	117.±14.4	9.75	103.63±8.13	Clinic	Y	P	Go/NoGo, Stroop
Xu et al. (2011)	DSM-IV	39/35	107.22±14.1	6-13	IQ>70	Clinic	NI	P	WISC-R

Study	DSM Criteria	ADHD/ TD(n)	Avg. Age(m)	Age (yrs)	Avg.FIQ[b]	Sample Method[c]	Medica -tion Control	Public -ation	EF Measures[f]
Yang et al. (2008a, 2012a)[h]	DSM-IV	100/100	101.1	NI	98.52±11.29	Clinic	Y	P	SCWT, C-WISC, SST
Yang et al. (2011a)	DSM-IV	100/100	101.±1.27	6-12	98.52±1.41	Clinic	Y	P	Go/NoGO, DSFW/BW, Corsi Blocks Task, SCWT,SST
Yang et al. (2011b)	DSM-IV	91/54	95.1±7.24	6-8	97.69±11.64	Clinic	Y	P	Go/NoGo, DSFW/BW,SCWT, Corsi Blocks, Stop-signal(SST)
Yang et al. (2008b)	DSM-IV	26/30	98.11±34.23	3.3-13.5	109.96[a]	Clinic	NI	P	WCST-128[d], VS
Yang et al. (2012b)	DSM-IV	142/46	115.20±23.11	7-14	104.09±14.31	Clinic	Y	P	RCFT, DS, TMT, ToH, VF, SCWT,
Yao & Li (2003)	DSM-IV	45/45	123.18±32.12	7-14	NI	Clinic	NI	P	C-WISC,WCST-128[d]
Yao (2007)	DSM-IV	90/90	123.18±32.12	7-14	NI	Clinic	NI	P	C-WISC, WCST-128[d]
Zhang et al. (2010a, 2010b)[h]	DSM-IV	114/76	149.11±32.4	7-16	NI	Clinic	Y	P	WCST-128, CPT, Stroop-Golden
Zhou et al. (2005)	DSM-IV	113/83	120	8-12	NI	School	Y	P	WCST-128[d]

a. IQ standard score of Gong 's Non—verbal Intelligence Test, GNIT; **b.** Average IQ: NI=No sufficient information reported; **c.** Standard FIQ score was assessed by Raven's Progressive Matrices (J.C Raven, 1936)**d.** measure was conducted manually**; e.** Medication control: Y, Has medication control before conducted EF tasks; N, No medication control before conducted EF tasks; NI, No Information; f. Publication type of article: P, Published journal; D, Dissertation. g.relevant EF tasks conducted in the study. References of measure see Table 1.

Appendix B. The Forrest Plot of Overall EFs in Two Cultures (k=73)

Model	Group by Country	Study name	Subgroup within study	Comparison	Outcome	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	CH	Cao, 2011	ADHD	SimstrpCr%	inhib	0.96	0.26	0.07	0.45	1.47	3.67	0.00
	CH	Chan et al., 2006	ADHD	wcstPEr	set	0.19	0.30	0.09	-0.39	0.77	0.65	0.52
	CH	Gau & Chiang, 2013	ADHD	Combined	Combined	0.57	0.08	0.01	0.42	0.72	7.37	0.00
	CH	Gau & Shang, 2010	ADHD	Combined	Combined	0.46	0.10	0.01	0.27	0.65	4.67	0.00
	CH	Gau et al., 2009	ADHD	Combined	Combined	0.26	0.19	0.04	-0.12	0.64	1.34	0.18
	CH	Hang et al., 2010	ADHD	wcstPEr%	set	1.21	0.21	0.04	0.79	1.63	5.71	0.00
	CH	He & Jing, 2006	ADHD	wcstPEr	set	0.38	0.18	0.03	0.02	0.74	2.05	0.04
	CH	He & Jing, 2008	ADHD	DSBW	verbal wm	0.40	0.18	0.03	0.04	0.76	2.19	0.03
	CH	Jin et al., 2009	Combined	Combined	Combined	0.65	0.25	0.06	0.16	1.14	2.60	0.01
	CH	Jin et al., 2010	Combined	GocomiEr%	inhib	0.43	0.25	0.06	-0.07	0.92	1.70	0.09
	CH	Lan S. et al., 2011	Combined	Combined	Combined	0.43	0.06	0.00	0.31	0.55	6.89	0.00
	CH	Li Y, 2007	ADHD	Combined	Combined	0.55	0.14	0.02	0.28	0.82	4.05	0.00
	CH	Li J., 2009	ADHD	Combined	Combined	1.27	0.33	0.11	0.62	1.91	3.84	0.00
	CH	Li JY et al., 2005	ADHD	Combined	Combined	0.79	0.26	0.07	0.27	1.30	3.01	0.00
	CH	Li Qq et al., 2008	Combined	Combined	Combined	0.70	0.11	0.01	0.48	0.93	6.11	0.00
	CH	Lin et al., 2012	Combined	Combined	Combined	0.36	0.16	0.03	0.05	0.67	2.29	0.02
	CH	Liu & Wang, 2002	Combined	Combined	Combined	0.77	0.20	0.04	0.38	1.16	3.86	0.00
	CH	Liu & Wang, 2004	Combined	Combined	Combined	0.64	0.17	0.03	0.31	0.98	3.78	0.00
	CH	McAlonan G.,2009	ADHD	SSRT	inhib	0.62	0.29	0.08	0.06	1.18	2.18	0.03
	CH	Ou W et al., 2012	ADHD	Combined	Combined	0.53	0.22	0.05	0.11	0.95	2.47	0.01
	CH	Qian et al., 2010	Combined	Combined	Combined	0.24	0.11	0.01	0.03	0.45	2.27	0.02
	CH	Shi et al., 2007	Combined	wcstPEr	set	0.45	0.12	0.01	0.22	0.68	3.84	0.00
	CH	Shi et al., 2008	Combined	stropRt	inhib	0.38	0.07	0.00	0.24	0.52	5.37	0.00
	CH	Shuai & Wang, 2007	Combined	Combined	Combined	0.69	0.23	0.05	0.24	1.15	2.99	0.00
	CH	Shuai & Wang, 2007b	Combined	Combined	Combined	0.49	0.21	0.05	0.07	0.91	2.29	0.02
	CH	Tu, 2010	ADHD	Combined	inhib	0.38	0.26	0.07	-0.12	0.89	1.49	0.14
	CH	Wang SH, 2009	ADHD	SimstrpCr%	inhib	0.72	0.25	0.06	0.23	1.21	2.89	0.00
	CH	Wang XF, 2007	ADHD	Combined	inhib	1.25	0.27	0.08	0.71	1.78	4.54	0.00
	CH	Wang Y, 2007	ADHD	Combined	Combined	0.51	0.18	0.03	0.16	0.86	2.87	0.00
	CH	Wei, 2009	Combined	Combined	Combined	1.21	0.21	0.05	0.79	1.63	5.70	0.00
	CH	Wen et al., 2010	ADHD	Combined	Combined	1.08	0.32	0.11	0.44	1.72	3.33	0.00
	CH	Wu et al., 2012	ADHD	wcstPEr%	set	1.49	0.26	0.07	0.99	1.99	5.83	0.00
	CH	Xiao T et al., 2012	ADHD	Combined	Combined	0.47	0.35	0.12	-0.22	1.16	1.34	0.18
	CH	Xu et al., 2011	ADHD	DSBW	verbal wm	0.73	0.24	0.06	0.26	1.20	3.06	0.00
	CH	Yang BR et al., 2011a	ADHD	Combined	Combined	0.48	0.14	0.02	0.20	0.77	3.36	0.00
	CH	Yang BR et al., 2011b	Combined	Combined	Combined	0.92	0.16	0.03	0.60	1.23	5.69	0.00
	CH	Yang J et al., 2008	ADHD	wcstPEr	set	0.32	0.27	0.07	-0.20	0.84	1.21	0.23
	CH	Yang L et al., 2011	Combined	Combined	Combined	0.81	0.14	0.02	0.54	1.08	5.83	0.00
	CH	Yangbr	ADHD	Combined	Combined	0.64	0.14	0.02	0.36	0.92	4.42	0.00
	CH	Yao and Li, 2003	ADHD	wcstPEr	set	1.38	0.23	0.05	0.93	1.84	5.94	0.00
	CH	Yao, 2007	ADHD	wcstPEr	set	0.46	0.15	0.02	0.16	0.75	3.04	0.00
	CH	Zhang et al., 2010	ADHD	Combined	Combined	0.41	0.15	0.02	0.12	0.70	2.74	0.01
	CH	Zhou et al., 2005	Combined	wcstPEr	set	0.56	0.12	0.01	0.34	0.79	4.85	0.00
Fixed	CH					0.55	0.02	0.00	0.50	0.59	23.94	0.00
Random	CH					0.61	0.04	0.00	0.53	0.69	15.21	0.00
	NA	Alford, 2006	ADHDC	Combined	Combined	0.74	0.27	0.07	0.22	1.26	2.77	0.01
	NA	Babb et al., 2010	Combined	wcstPEr	set	0.60	0.25	0.06	0.11	1.09	2.40	0.02
	NA	Bidwell et al., 2004	ADHD	Combined	Combined	0.61	0.08	0.01	0.45	0.78	7.27	0.00
	NA	Biederman et al., 2004	ADHD	Combined	Combined	0.49	0.09	0.01	0.31	0.68	5.33	0.00
	NA	Cantrill, 2003	ADHD	stropinter	inhib	1.07	0.28	0.08	0.52	1.62	3.79	0.00
	NA	Closson, 2010	ADHD	Combined	Combined	0.26	0.28	0.08	-0.29	0.81	0.93	0.35
	NA	Edmonds, 2007	Combined	Combined	Combined	0.84	0.27	0.07	0.31	1.37	3.12	0.00
	NA	Garaas, 2007	Combined	Combined	Combined	0.56	0.27	0.07	0.03	1.09	2.06	0.04
	NA	Goldberg et al., 2005	ADHD	Combined	Combined	0.33	0.28	0.08	-0.22	0.88	1.18	0.24
	NA	Hale et al., 2009	ADHD	Combined	set	0.52	0.20	0.04	0.13	0.92	2.61	0.01
	NA	Huang-Pollock et al., 2009	Combined	Combined	Combined	0.57	0.18	0.03	0.22	0.93	3.17	0.00
	NA	Hummer et al.,2011	ADHDDBD	Combined	Combined	0.42	0.28	0.08	-0.13	0.97	1.49	0.14
	NA	Karalunas et al., 2011	ADHD	SSRT	inhib	0.88	0.22	0.05	0.45	1.31	4.03	0.00
	NA	Loftis, 2004	Combined	Combined	Combined	0.55	0.21	0.04	0.14	0.95	2.64	0.01
	NA	Mahone et al., 2005	ADHD	Combined	Combined	0.57	0.23	0.05	0.12	1.01	2.50	0.01
	NA	Martel, 2009	ADHD	Combined	Combined	0.34	0.11	0.01	0.12	0.56	2.97	0.00
	NA	Miller et al., 2012	ADHD	Combined	Combined	0.33	0.14	0.02	0.06	0.60	2.42	0.02
	NA	Mullane et al., 2007	ADHD	Combined	Combined	0.71	0.37	0.14	-0.01	1.43	1.93	0.05
	NA	Naidoo, 2007	Combined	DS	verbal wm	0.94	0.26	0.07	0.43	1.44	3.65	0.00
	NA	O'Brien et al., 2010	ADHD	Combined	Combined	0.39	0.17	0.03	0.05	0.72	2.28	0.02
	NA	O'Donnell, 2004	Combined	Combined	Combined	0.47	0.19	0.03	0.11	0.83	2.55	0.01
	NA	Peden, 2010	ADHD	Combined	Combined	0.69	0.25	0.06	0.21	1.17	2.80	0.01
	NA	Schuster, 2005	ADHD	Combined	Combined	0.34	0.26	0.07	-0.17	0.85	1.31	0.19
	NA	Semrud-Clikeman et al., 2008	Combined	Combined	inhib	0.66	0.20	0.04	0.27	1.05	3.31	0.00
	NA	Semrud-Clikeman et al., 2010	Combined	Combined	Combined	0.20	0.19	0.04	-0.17	0.57	1.08	0.28
	NA	Walkowiak, 2008	Combined	Combined	Combined	0.51	0.22	0.05	0.07	0.95	2.27	0.02
	NA	Willcutt et al., 2005b	Combined	Combined	Combined	0.65	0.10	0.01	0.45	0.84	6.62	0.00
	NA	Wodka et al., 2007	ADHD	GocomiEr%	inhib	0.44	0.19	0.04	0.06	0.82	2.25	0.02
	NA	Wodka et al., 2008	ADHD	Combined	Combined	0.45	0.18	0.03	0.09	0.81	2.47	0.01
	NA	Youngwirth et al., 2007	Combined	Combined	Combined	0.51	0.20	0.04	0.12	0.90	2.56	0.01
Fixed	NA					0.53	0.03	0.00	0.47	0.59	16.73	0.00
Random	NA					0.53	0.03	0.00	0.47	0.59	16.73	0.00
Fixed	Overall					0.54	0.02	0.00	0.51	0.58	29.20	0.00
Random	Overall					0.56	0.02	0.00	0.51	0.61	22.56	0.00



Appendix C. Mean Effect Size of Planning in North American and Chinese Studies (n=30)

Study	North American				Study	Chinese		
	ROCF[a]	ToL[c]	DTower[d]	SOC[e]		ToL[a]	ToH[a]	SOC[a]
Huang-Pollock et al., (2009)	0.79[b]				Li (2009)	0.77		
Closson (2010)		0.2			Lin et al. (2012)			0.41
Garaas (2007)		0.28			Li et al. (2005)	0.67		
O'Brien et al. (2010)			0.39		Qian et al. (2010)		0.09	
Semrud-Clikeman et al. (2010)			0.23		Shuai et al. (2011)		0.3	
Wodka et al., (2008a,2008b)			0.56		Shuai & Wang (2007a)		0.78	
Peden (2010)			0.95		Shuai & Wang (2007b)		0.36	
Walkowiak (2008)			0.35		Gau et al. (2009)			0.38
Loftis (2004)			0.74		Gau & Shang (2010)			0.5
Edmonds (2007)			0.12					
Goldberg et al. (2005)				0.34[b]				
Weighted mean effect size	0.79[b]	0.24	0.47	0.34[b]		0.71	0.32	0.46
±95% confidence interval	0.43,1.15	-0.14,0.62	0.28,0.66	-0.21,0.88		0.32,1.1	0.11,0.53	0.31,0.61
Number of studies that found a significant group difference ($p<0.05$)	1/1	0/2	4/7	1/1		2/2	2/4	2/3
%	100%	0	57%	100%		100%	50%	67%
Homogeneity Index: *p*	1	0.83	0.15	1		0.81	0.05	0.79
Homogeneity Index: Qt	0	0.05	9.5	0		0.06	7.94	0.46

a. copy condition in ROCF task; b. effect size obtained from one study.

Appendix D. Mean Weighted Effect Sizes for Complex Function Tasks in North American Studies

NA Study	Complex[a]	
	DCWI4[b]	DVF3[c]
Alford (2006)	0.82	
Semrud-Clikeman et al. (2010)	0.22	
O'Brien et al. (2010)	0.52	
Peden (2010)	0.56	0.88
Walkowiak (2008)	0.39	
Wodka et al. (2008a, 2008b)	0.55	0.23
Loftis (2004)		0.46
Weighted mean effect size	0.48	0.49
±95% confidence interval	0.32, 0.65	0.13, 0.84
Number fo studies that found a significant group difference ($p<0.05$)	4/6	2/3
%		
Homogeneity Index: p	0.56	0.11
Homogeneity Index: Qt	3.94	4.35

a. These task condition measures working memory, set shifting and inhibition response as comprehensive function.

Appendix E. Mean Effect Size of Verbal Fluency in North American and Chinese Studies

Study	North American		Study	Chinese	
	Letter Fluency	Categorical Fluency		Letter Fluency	Categorical Fluency
	VFTp/DKEFS VFC1	VFTc/DKEFS VFC2		VFTp	VFTc
Edmonds (2007)	0.33		Li et al. (2008)		0.09
Peden (2010)	0.24	0.94	Yang et al. (2012b)		0.63
Schuster (2005)	0.22	0.57	Raymond et al. (2005)	0.08[a]	
Wodka et al. (2008a, 2008b)	0.54	0.33	Shuai et al. (2011)		0.14
Garaas (2007)	0.43	0.36	Shuai & Wang (2007a)		0.33
			Shuai & Wang (2007b)		0.16
Weighted mean effect size	0.38	0.52		0.08[a]	0.26
±95% confidence interval	0.17, 0.59	0.25,0.8		-0.5,0.66	0.05,0.46
Number of studies that found a significant group difference (p<0.05)	1/5	2/4		0/1	2/5
%	20%	50%		0	40%
Homogeneity Index: p	0.82	0.25		1	0.02
Homogeneity Index: Qt	1.55	4.15		0	12.32

a. VFT= Verbal Fluency Test, p=phonemic, c= categorical; DKEFS VFC1/2= Verbal Fluency test Condition 1/Condition 2 from D-KEFS.