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Neuropsychological Evaluation of Deficits in Executive Functioning for ADHD Children With or Without Learning Disabilities

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This study investigates multiple aspects of executive functioning in children with attention deficit/hyperactivity disorder (ADHD). These areas include attentional components, impulsiveness, planning, and problem solving. The rationale of the study is based on neurophysiological studies that suggest frontal lobe dysfunction in ADHD. As frontal lobe functioning is related to abilities in executive control, ADHD is hypothesised to be associated with deficits in various areas of executive functioning. The specific effect of comorbidity of learning disability (LD) was also investigated. Eighty-three children with ADHD and 29 age-matched controls (age 7–13) participated in the study. A battery of neuropsychological tests was utilized to evaluate specific deficits in speed of processing, selective attention, switching attention, sustained attention, attentional capacity, impulsiveness, planning and problem solving. Findings indicated that children with ADHD have slower verbal responses and sustained attention deficit. Deficits in selective attention and attentional capacity observed were largely related to the presence of LD. No specific deficit associated with ADHD or the comorbidity of LD was identified in switching attention,

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impulsiveness, planning, and problem solving. These results revealed that ADHD is not associated with a general deficit in executive functioning. Instead, ADHD is related to a specific deficit in regulation for attentional resources. The importance of isolating the deficit related to LDs for examining the specific deficit associated with ADHD is highlighted. Results also emphasised the importance of isolating the effect of lower level of abilities (e.g., speed of processing) and the utilization of specific definition for the examination of executive functions.

Attention deficit/hyperactivity disorder (ADHD) is among one of the most studied childhood disorders. Tannock (1998) noted that the Medline and Psychlit databases each list approximately 4,000 peer-reviewed articles published since 1966. However, research on ADHD has yielded inconsistent results and was limited by a number of issues. It is difficult to differentiate ADHD from other childhood disorders in terms of its aetiology, course, characteristics, and response to treatment (Schachar, 1991). One of the major reasons for this state of confusion lies in the definition of the deficits associated with ADHD and the measures available to examine these deficits specifically.

Comorbidity in ADHD is also a complicating factor that exists in all aspects of research in ADHD. The most frequent comorbidity found in ADHD includes oppositional defiant disorder, or conduct disorder (Loeber, 1990), and learning disability (LD; Ackerman & Dykman, 1990; Stanford & Hynd, 1994). The comorbidity of LD has been known and described since the 1970s. Comorbidity rates reported have ranged from 10 to 92% (Biederman, Newcorn, & Sprich, 1991).

This study investigates the specific cognitive deficits associated with ADHD from a framework that conceptualizes executive functioning as a multifaceted construct. The specific effect related to the comorbidity of LD was also isolated in the examination of the specific deficit associated with ADHD.

LIMITATIONS OF EXISTING MEASURES

According to recent extensive reviews of studies that examined the aetiology of ADHD, the most widely accepted interpretation of the present neurophysiological findings regarding ADHD is that fronto-striatal networks may be involved (Castellanos, 1999; Tannock, 1998). In a comprehensive review of studies examining executive functioning associated with ADHD, it was reported that consistent deficits in executive functioning tasks are found in ADHD samples, thus implicating prefrontal regions of the brain in ADHD (Pennington & Ozonoff, 1996). However, such evidence has to be accepted with caution, as there are a number of limitations in neurophysiological studies for ADHD (e.g., small sample size, participant selection, and disregard of comorbidity).

Studies based on interpretation of performance in tests that are purported to measure executive functions have also yielded inconsistent results. The Wisconsin Card Sorting Test (WCST; Berg, 1948; Grant & Berg, 1948) is one of the most common clinical tests for examining switching attention, an important component of executive function. In some studies using WCST to assess switching attention of ADHD children, ADHD was found to be associated with a deficit in switching attention (Boucagnani & Jones, 1989; Chelune, Ferguson, Koon, & Dickey, 1986; Gorenstein, Mammato, & Sandy, 1989; Grodzinsky & Diamond, 1992; Johnson, 1991; Loge, Staton, & Beatty, 1990; Shue & Douglas, 1989). However, negative findings have also been documented in other studies (Barkley, Grodzinsky, & DuPaul, 1992; Reader, Harris, Scherholz, & Denckla, 1994). As commented by Mountain and Snow (1993), who reviewed the literature on WCST, it is essential to note that interpretation of performance on such a test, which is purported to measure executive functions, has to be cautious. A variety of processes and brain structures are responsible for performance on this test. Thus, WSCT is not able to specify the nature of any underlying specific attentional deficit in ADHD.

The Go/No-Go test has also been applied to evaluate the inhibitory component of executive functions for ADHD children. In one of the studies, ADHD children were found to make more commission and omission errors than controls. They also committed more multiple omission errors (up to three) than controls (Trommer, Hoeppner, Lorber, & Armstrong, 1988). The finding that ADHD children make more commission and omission errors than controls were also replicated by another study (Shue & Douglas, 1989, 1992). However, the reliance of the Go/No-Go test to assess inhibitory functions has a number of limitations. In some of the studies (e.g., Shue & Douglas, 1989, 1992; Trommer et al., 1988), the measures derived from the test only include commission and omission errors, and reaction time (RT) is not measured. A participant's RT to the primary task may become a significant confounding factor that affects the probability of committing such errors. Moreover, only two blocks of 10 trials: five with go signals (i.e., one tap) and five with a no-go signal (two taps) were used in a study using the test (Trommer, Hoeppner, & Zecker, 1991). The interval between taps for the no-go stimulus was fixed at one single interval (i.e., 250 ms). Thus, participants may adopt the strategy of delaying their response in order to wait for the stop signal. These confounding factors were controlled in studies utilizing the stop signal paradigm (Logan & Cowan, 1984; Logan, Cowan, & Davis, 1984), which represents a more sophisticated experimental paradigm for evaluating response inhibition for ADHD children. However, the tasks are often characterized by lack of sufficient norms, especially for children.

The Stroop Color and Word test (Golden, 1987) has been utilized to measure selective attention associated with ADHD. According to a review, five out of six studies that used the Stroop test were able to distinguish ADHD participants from control participants by using the Stroop interference measure (Barkley et al., 1992). Two more recent studies (Leung & Connolly, 1996; Pennington, Grossier, & Welsh, 1993) also reported a significant difference in the Stroop interference measure between ADHD and control children. However, Seidman, Biederman, Faraone, Weber, and Oullette (1997) reported that the critical Stroop interference score failed to differentiate ADHD children when scores were adjusted for confounding factors such as socioeconomic status, family history, and comorbidity.

In summary, assessment measures for general executive functioning (e.g., the WCST and Go/No-Go test) can be multidetermined, so that a single score or general performance on a task is related to the functioning of a number of cognitive domains. Thus, utilization of tests that enabled component analysis is essential in the investigation of the specific deficit in executive functioning for ADHD. Also, the utilization of specific measurements that eliminate the effect caused by difference in lower level abilities (e.g., speed of responding) is required. It is also important to adjust the effect related to confounding factors, such as socioeconomic status and comorbidity.

Comorbidity of LD and Attention

Shaywitz and Shaywitz (1991) noted that the diagnosis of ADHD is established by a history of inattention, impulsivity and hyperactivity, whereas the diagnosis of LD is made on the basis of a discrepancy among tests of ability (e.g., IQ) and performance on tests of achievement. They concluded that naming and linguistic fluency deficits reflect reading disability, whereas verbal learning and memory deficits are linked to attention disorder. They also proposed that ADHD and LD are distinct disorders, though they occur together in a large number of children. Given that the definitions for ADHD and LD are based on independent assessment methods, investigation of the effect of the comorbidity of LD would avoid the assessment confusion found between ADHD and conduct disorder. However, despite this benefit and the awareness of the relationship between ADHD and LD, Jensen, Martin, and Cantwell (1997) noted that evidence of the comorbidity between ADHD and LD accumulated so far remains inconclusive. They also proposed that measures to assess the different aspects of attention and working memory are needed to distinguish subtypes of ADHD by comorbidity.

Thus far, few researchers have addressed the unique difficulties in components of executive functioning (i.e., attention and response inhibition) experienced by children with ADHD when LD is also present. It is plausible that both ADHD and LD are associated with deficits in the same component of executive functioning. Thus, children with pure ADHD perform more poorly than normal controls, whereas children with ADHD and the comorbidity of LD perform more poorly than the pure ADHD group. It is also probable that ADHD and LD are associated with deficits in different executive components. In fact, these possibilities are supported by previous research.

First, attentional deficits associated with LD are suggested in previous studies. For example, Cermak and his colleagues (Cermak, Goldberg, Cermak, & Drake, 1980; Cermak, Goldberg-Warter, DeLuca, Cermak, & Drake, 1981) have documented the information processing deficits in children with LDs by utilizing a series of information-processing tasks in the laboratory. They found that the rate and level at which children with LDs process information are below the standards set by normal controls. There is also substantial evidence that indicates that LD is a reflection of central nervous system disturbance (for a review see Hynd, Marshall, & Gonzalaz, 1991). In a recent study utilizing parental report of children with and without LD, results indicate that children with LDs have significantly more neurodevelopmental problems or delays across domains (e.g., language, motor, attention, and social behavior) than normal controls (Blumsack, Lewandowski, & Waterman, 1997). However, the attentional deficits associated with LD suggested in these studies are not specific. Swanson (1993) conducted a study on specific attentional deficit associated with LDs. Verbal and visuospatial working memory measures were used in the study to examine the effect of LD. Results indicate that children with LDs suffer generalized working-memory deficits, possibly due to storage constraints in the executive system. Thus, according to these previous studies, LD itself is probably associated with attentional deficits. Therefore, research on ADHD that has not taken the effect of LD into consideration may have wrongly attributed the associated deficit of LD to ADHD.

Prior to the review by Biederman et al. (1991), few researchers had undertaken any systematic examination of ADHD children with and without LDs. The few studies that undertook this effort failed to find differences between comorbid and noncomorbid groups. In fact, the distinction between ADHD and LD has been called into question by earlier studies (Halperin, Gittelman, Klein, & Rudel, 1984; Prior & Sanson, 1986). Prior and Sanson (1986) argued that there is little evidence from past research to support the tenet that ADHD and LD can be differentiated on the basis of attentional deficits. However, there are studies that show that ADHD and LD are related to different specific attentional deficits. In a study utilizing an information processing framework (Meere, Baal, & Sergeant, 1989), results indicate that LD is associated with particular difficulty in the central stages of processing (i.e., memory and decision, indicative of a divided attentional deficit), whereas ADHD is associated with difficulty in motor response. Thus, both groups exhibited slower RT when compared to the control group, but due to different underlying deficits. In another study, it was found that ADHD children with and without reading disability can be differentiated from the normal controls on laboratory measures of sustained attention and impulse control (Dykman & Ackerman, 1991). As children with reading disability show poorer performance than those without reading disability, these researchers advocate the importance of assessing LD in ADHD.

Most of the experimental research until recently has ignored the coexistence of LD in ADHD. For example, in a study aiming to differentiate children with ADHD from normal controls by using neuropsychological and behavioral assessment, coexistence of other childhood pathologies were not taken into consideration (Pieneda, Ardila, & Rosselli, 1999). Thus, even though findings indicate that children with ADHD can be reliably discriminated from normal controls in test measures, it is not certain if the difference between the ADHD and control groups was due to ADHD or other comorbidities.

As suggested by Hinshaw and Park (1999), ADHD children with or without comorbid psychopathology (e.g., LD), may differ radically with respect to causal factors, correlates, course, and treatment response. Thus, research that screens for comorbidity of LD is important with respect to the understanding of ADHD. The presence of a coexisting disorder such as LD may also necessitate different treatment regimes (Del Dotto, 1993). Through careful screening of ADHD children for LD, this study attempts to differentiate the specific deficits associated with ADHD and the comorbidity of LD in various components of executive functioning.

Theories for ADHD

The findings that suggest inhibitory or executive dysfunction in ADHD are consistent with the executive dysfunction theory of ADHD developed by Barkley (1994, 1997, 1999). According to the model, behavioral inhibition is the primary deficit in ADHD, specifically for the subtypes with hyperactivity (i.e., the predominantly hyperactive-impulsive type and the combined type). The model hypotheseses that ineffective execution of behavioral inhibition leads to secondary impairments in four executive neuropsychological abilities. The four executive functions affected by behavioral inhibition are working memory, self-regulation of affect-motivation-arousal, internalization of speech, and reconstitution. In turn, these executive functions interfere with effective self-regulation and adaptive functioning. Because the four executive functions encompass concepts of behavioral inhibition, executive functions and self-regulation, evidence pointing to deficits related to ADHD in any of these areas can be seen as support for the theory. Barkley also referred to the often observed behavior of ADHD children with hyperactivity, such as excessive and impulsive responding in interpersonal communication, as evidence for these children's inability to delay responding. According to this theory, ADHD children of these types are capable of performing appropriately if they allow themselves the time to do so. However, they usually fail to inhibit their responses before they have had enough time to assess the task and arrive at the correct response. Thus, the theory accounts for impulsive errors, but does not explain so easily why ADHD children of these types are often found to be slow and variable in RT tasks.

The reliance on the concept of executive functions in the executive dysfunction theory of ADHD helps to unify and explain evidence pointing to the attentional and inhibitory deficits identified for ADHD children. However, there is also growing dissatisfaction with the "catch-all" characteristics of the concept. As commented by Douglas (1999), tasks that are specifically designed to measure attention and inhibition are usually cited in reviews of measures for executive functions (e.g., Barkley et al., 1992; Swanson et al., 1998). Thus, it is necessary to establish conceptual and theoretical clarity in the study of executive functions, and to develop sensitive and specific instruments for measuring them (Denckla, 1996; Morris, 1996). If executive functioning leaves as a vague and catch-all concept for all higher order abilities, it would remain as a nonspecific variable that is hard to be examined. It would also be hard to differentiate specific deficits in executive control associated with various clinical populations. Perhaps, as many investigators have suggested, the use of tasks that lend themselves to the analysis of specific cognitive processing mechanism, rather than the vague supraordinate or higher order concepts, will be better in the understanding of specific deficits associated with ADHD (Cohen & Servan-Schreiber, 1992; Denckla, 1996).

The resource allocation hypothesis for ADHD offered an alternative explanation for the deficits observed in ADHD children (Sergeant & Meere, 1990a, 1990b; Sergeant, Oosterlaan, & Meere, 1999). Based on Sternberg's (1969, 1975) additive-factors model and Sander's (1983, 1977) cognitive-energetic model of information processing, Sergeant and Meere (1990a, 1990b, 1994) proposed that ADHD children are deficient in the motor response stage of information processing. According to the cognitive-energetic model (Sanders, 1983, 1977), there are three energetic pools in information processing (i.e., arousal, activation, and effort). These investigators used experimental manipulation of attentional variables to increase processing demands at the encoding and searching stages of Sternberg's model. These studies did not find that ADHD children's performance is more impaired than that of controls; thus the notion that attentional or executive problems are associated with ADHD was rejected. They also attribute the slow and variable RT identified for ADHD children as reflecting deficits in the output stage of information processing (Sergeant & Meere, 1990a, 1990b, 1994).

More recently, within the context of the cognitive-energetic model (Sanders, 1983, 1977), these investigators suggested that the deficit of ADHD is on state regulation. The basic argument of this model is that ADHD is not associated with attentional deficit; instead, they have a deficit in the allocation or regulation of effort, activation, or both, which they termed as state regulation deficit (Meere, 1996; Sergeant et al., 1999). According to these investigators, the concept of state refers to the overall level of alertness of the participant (Posner, 1978). State regulation, in turn, refers to "energy mobilization," which is necessary to change the state of the participant in the direction that is optimal for a task or situation, such was referred to be “the required or target state” (Hockey, 1979). Therefore, performance deficiencies may reflect mismatches between the actual state of the participant and the state required for performing a particular task. Under this model, motivation and environmental factors can be important variables that may affect state regulation, and thus contribute to the problems observed in ADHD children.

Aims of This Study

To untangle the nonspecific and catch-all characteristics of executive function, attention, which is another term often used for describing executive function, is conceptualized as a multifaceted construct in this study. This is consistent with current findings in neuroscience that suggest that distinct brain regions and networks may be involved in different forms of attention. For example, Posner and colleagues proposed on the basis of functional imaging studies that there were at least three attentional systems within the brain, which can be characterized as selective attention, sustained attention, and spatial attention (Posner & Raichle, 1994). On the basis of data derived from performance on neuropsychological tests, Mirsky and his colleagues (Mirsky, 1996; Mirsky, Anthony, Duncan, Ahearn, & Kellam, 1991) have provided a model of attention that contains five distinct elements. The five elements include focused attention, shift attention, sustained attention, encoding capacity, and attentional stability.

In this study, a battery of neuropsychological tests that allowed component analysis of specific cognitive processing mechanisms (i.e., speed of processing, various attention components, impulsiveness, planning, and problem solving) was utilized. Most of these measures allowed the isolation of effect associated with lower level abilities (e.g. speed of processing) when a specific higher level of cognitive component was examined. These findings were compared with the predictions of the two major models for ADHD. According to the resource allocation hypothesis (Sergeant & Meere, 1990a, 1990b; Sergeant et al., 1999), ADHD is associated with problems in utilizing attentional capabilities in an optimal manner, but is not associated with real attentional incapabilities. Thus, children with ADHD are expected to have slower RT. They may also have lower ability in sustaining attention for a single task due to problems in regulating their alertness. However, systematic deterioration of performance related to increased demand in executive control is not expected. According to the executive dysfunction model for ADHD (Barkley, 1994, 1997, 1999), children with ADHD are predicted to have real deficits in executive functioning. Therefore, children with ADHD are hypothesised to have problems in various components of executive control.

LD is one of the most common comorbidities for ADHD (Ackerman & Dykman, 1990; Stanford & Hynd, 1994), and is by itself related to information processing deficits (Cermak et al., 1980; Cermak et al., 1981). It is essential to examine whether the deficits observed in children with ADHD are actually related to ADHD or LD. In this study, the specific effect related to the comorbidity of LD was investigated.

METHOD

Participants

This study involved three groups of children: 58 with ADHD but not LD (ADHD–LD), 25 with ADHD and LD (ADHD+LD), and 29 in the community control group. They were age 7 to 13. IQ was estimated by using a short form of the Wechsler Intelligence Scale for Children–Third Edition (WISC–III; Wechsler, 1991) consisting of the Similarities, Vocabulary, Block Design and Object Assembly subtests. Only those with an overall estimated IQ greater than or equal to 85 were recruited as subjects in the present study. All children were assessed for LD, and this information was used to determine comorbidity of LD with ADHD. These participants had also participated in the investigation for the specific deficits associated with ADHD utilizing experimental measures of the task–set switching paradigm and stop signal paradigm (Wu, Allport, Castiello, & Anderson, 2002a, 2002b, 2002c).

The ADHD children were recruited from referrals mainly from the Royal Children's Hospital in Melbourne, Australia. ADHD was defined by information provided by referrers and parents to avoid the possibility of false positives in identification. The referrers were pediatricians who diagnosed the ADHD children based on Diagnostic and Statistical Manual of Mental Disorders (4th ed. [*DSM–IV*]; American Psychiatric Association, 1994) criteria. Moreover, the Behavioral Assessment System for Children–Parent Rating Scale (BASC–PRS; Reynolds & Kamphaus, 1992) was utilized to collect information regarding to the child's behavior before they were invited to participate in the study. This study included only those children who had either one or both of the scores in the Attention Problems and Hyperactivity subscales of the BASC–PRS greater than the 90th percentile.

The BASC–Teacher Rating Scale (BASC–TRS; Reynolds & Kamphaus, 1992) was not used for the screening procedure because children in this study were not recently diagnosed as having ADHD, all had been prescribed stimulant medication for their ADHD symptoms during school hours before they were recruited for the present study. The effect of stimulant medication in improving their behavior in school may have affected their results in BASC–TRS. In fact, many parents of these ADHD children who took part in this study have also reported that the behavioral improvements of their children in school after taking the stimulant medication has greatly affected their ratings in the BASC–PRS as well. Moreover, all the ADHD participants were initially diagnosed by clinicians as having ADHD based on *DSM–IV* criteria prior to referral to the study. As stated in *DSM–IV*, the manifestation of ADHD symptoms in multiple situations is required for making the diagnosis. Therefore, the administration of the BASC–PRS was done only for the sake of this study and after the diagnosis of ADHD has been made based on *DSM–IV* criteria. The reliance on the BASC–PRS for further screening was also justified by the finding that Australian parents were found to be more conservative, indicating fewer symptoms in a questionnaire than in a structured face-to-face interview (Levy, Hay, McStephen, Wood, & Waldman, 1997).

Comorbidity of LD was derived when any of the scores in the Spelling and Reading subtests of the Wide Range Achievement Test–Third edition (WRAT–3; Wilkinson, 1993) was below or equal to the 16th percentile, and the standard score of any of the WRAT–3 subtests was 20 points below the estimated IQ. These stringent criteria for defining the comorbidity of LD were used because in previous studies, LD had been found to be overidentified in ADHD children if the defining criteria were liberal (Semrud-Clikeman et al., 1992). Based on these criteria, the ADHD group was classified into two subgroups according to the presence of the comorbidity of LD: (a) ADHD–LD for those who did not meet the criteria of LD, and (b) ADHD+LD for those who met the criteria of LD.

A stimulant (e.g., methylphenidate) was the only medication taken by all the clinical participants for ADHD symptoms. However, they were not on medication on the day of testing. Also, clinical participants recruited had no history of neurological problems.

The control participants were recruited from local state schools. They all met the following criteria: (a) no history of involvement with mental health services for behavioural or emotional problems by parent report; (b) no history of neurological problems; (c) scores on all subscales of the BASC–PRS did not exceed the 90th percentile of the appropriate age norms; and (d) scores on the WRAT and WISC–III did not meet the criteria of LD.

If the 90th percentile in the Hyperactivity and Attention Problems subscales of the BASC–PRS were used as the cutoff point for defining the subtypes of ADHD according to *DSM–IV*, most of the ADHD children recruited in the study would be classified as belonging to the combined subtype. The number of participants for different subtypes among the three participant groups was presented in Table 1. Significant differences in the percentile score for Attention Problems, $F(2, 109) = 128.70$, $p < .001$, and Hyperactivity, $F(2, 109) = 120.02$, $p < .001$, subscales were also identified. Post hoc tests revealed that the percentile scores for the ADHD–LD and ADHD+LD groups were significantly higher than that for the control group ($p < .05$). The mean and standard deviation of percentile for the Attention Problems and Hyperactivity subscales for the three participant groups were presented in Table 2.

There were altogether 92 boys and 20 girls. The distribution of boys and girls in the three participant groups (i.e., control, ADHD–LD, and ADHD+LD) was not significantly different from each other's, $\chi^2(2) = 1.51, p > .05$. The social status of the participants was defined according to the occupational levels of parents. The occupational level of parents was rated according to the 7-point Daniel's Scale of Occupational Prestige (Daniel, 1983), where a score of 1 reflects *high socioeconomic status* and a score of 7 refers to *low status*. There was no difference in mother's occupational status, $F(2, 109) = 1.23, p > .05$, and father's occupational status, $F(2, 109) = 2.96, p > .05$, for the three participant groups. There was no difference in age among the three participant groups, $F(2, 109) = .36, p > .05$. However, a significant group difference was found for estimated IQ, $F(2, 109) = 6.74, p < .01, ES = .11$. Post hoc tests revealed that

TABLE 1
Number of Participants for Different *DSM–IV* ADHD Types Among ADHD Participants Groups[a]

Subtype	*ADHD–LD*	*ADHD+LD*
Inattentive	9	2
Hyperactive-impulsive	7	4
Combined	42	19

Note. ADHD = attention deficit hyperactivity disorder; LD = learning disability.
[a]Based on the 90th percentile cutoff point on the Attention Problems and Hyperactivity subscales of the Behavioral Assessment System for Children–Parent Rating Scale.

TABLE 2
Means and Standard Deviations of Percentile Scores on Attention Problems and Hyperactivity Scale of the BASC–PRS, Age, IQ, Reading, and Spelling Scores for the Three Participant Groups

	Control		*ADHD–LD*		*ADHD+LD*	
	M	*SD*	*M*	*SD*	*M*	*SD*
PRS–hyperactivity	34.41	26.90	94.84	11.08	92.56	17.79
PRS–attention problems	44.62	25.75	94.37	8.60	96.40	3.69
Age	10.60	1.97	10.45	2.00	10.13	2.19
IQ[a]	113.65	12.80	103.32	12.80	105.64	11.04
Standard score for reading[b]	111.96	11.01	100.63	13.29	82.60	13.32
Standard score for spelling[b]	106.03	14.55	93.53	11.43	79.80	8.79

Note. BASC–PRS = Behavioural Assessment System for Children–Parent Rating Scale; ADHD = attention deficit hyperactivity disorder; LD = learning disability.
[a]Estimated IQ based on performance on the Wechsler Intelligence Scale–Third Edition. [b]Standard score based on performance on the Wide Range Achievement Test–Third Edition.

the IQ for the ADHD–LD group (M = 103, SD = 12) was significantly lower than that for the control group (M = 113, SD = 12, $p < .01$). The means and standard deviations of age, IQ, and standard scores of WRAT–3 subtests were presented in Table 2.

Neuropsychological Tests Measures

The battery of neuropsychological tests utilized included two subtests of the Test of Everyday Attention for Children (TEACH: Manly, Robertson, Anderson, & Nimmo-Smith, 1999), which included Sky Search and Code Transmission, (a) the Stroop Color and Word Test (Golden, 1987), (b) the Contingency Naming Test (CNT; Taylor et al., 1990), (c) Digit Span, from WISC–III (Wechsler, 1991), and (d) the Tower of London Test (TOL; Anderson, Anderson, & Lajoie, 1996). These tests were chosen because most of these tests were designed for children and had normative data available for the age range sampled in this study. These were considered important in this study because most neuropsychological tests were designed for use with adults and may not be appropriate for the child population. Also, according to previous studies, most of these tests can provide a rigorous measure of an identified component that rules out alternate explanations (e.g., Anderson, 2000; Anderson, Anderson, & Lajoie, 1996; Manly et al., 1999; Mirsky, 1996; Mirsky et al., 1991). A summary of the components corresponding to various neuropsychological test measures is presented in Table 3.

TABLE 3
The Components Measured by Various Neuropsychological Test Measures

Components	*Neuropsychological Test Measures*
Speed of processing	1. Stroop Color and Word Test: Color score
	2. Contingency Naming Test: Time score for Subtest 1
	3. Sky Search: Motor Control Time score
Selective attention	1. Sky Search: Attention score
	2. Stroop Color and Word Test: Stroop interference score
Switching attention	1. Contingency Naming Test: Switch time cost for Subtest 3
	2. Contingency Naming Test: Switch error cost for Subtest 3
	3. Contingency Naming Test: Switch time cost for Subtest 4
	4. Contingency Naming Test: Switch error cost for Subtest 4
Sustained attention	1. Code Transmission: Code total correct score
Attentional capacity	1. Digit Span: Forward score
	2. Digit Span: Backward score
Impulsiveness	1. Tower of London: total number of failed attempts
	2. Tower of London: total planning time
Planning and problem solving	1. Tower of London: total score

Task Requirements of Various Neuropsychological Tests

Sky Search. Sky Search is a subtest, from TEACH (Manly et al., 1999), for examining selective attention. Sky Search includes two conditions: (a) the Sky Search Attention Subtest, in which rows of spaceships are presented on a sheet of paper; the participant uses a pen to circle those pairs of spaceships that match with each other and ignore the other surrounding spaceships; and (b) the Sky Search Motor Control Subtest, in which the targets in Sky Search Attention are presented on a sheet of paper, without the presence of nontarget spaceships; the participant has to circle all these targets. The participant is required to complete the task as soon as possible for both subtests. The number of correctly identified targets and time taken for Sky Search Motor Control is used to estimate the speed of processing. The time taken per correctly identified targets for Sky Search Attention minus the same index for Sky Search Motor Control is used to estimate ability in selective attention. The subtraction of one timing score from the other provides a less contaminated measure of efficiency of selective attention.

The validity of Sky Search as a measure of selective attention has also been examined in a Structural Equation Model (Bentler, 1995) by Manly et al. (1999). According to this study, the hypothetical model of attention includes three factors: selective attention; attentional control or switching, and sustained attention. Sky Search was confirmed as a valid measure for selective attention.

Code Transmission. Code Transmission is another subtest from TEACH (Manly et al., 1999) for estimating the ability in sustained attention. The participant has to sustain his or her attention on a rather monotonous series of spoken numbers. The task is to listen out for two 5s in a row. Every time this happens the participant is required to say the number that came immediately before the fives. Three hundred sixty numbers from 1 to 9 are randomly presented from the audiotape over 12 min, and there are 40 code numbers altogether. The Code score (i.e., number of target code numbers identified) is utilized for measuring sustained attention. Because there are only 40 targets out of 360 items, the event rate of the target task is low. Thus, the task is sensitive to errors of omissions. Although there are 23 times in which a 5 would be presented without another 5 following it, the task is not found to be particularly sensitive to errors of commissions. The validity of Code Transmission as a measure of sustained attention was also confirmed by a previous study utilizing the technique of the Structural Equation Model (Manly et al., 1999).

Stroop Color and Word Test. The Stroop Color and Word Test (Golden, 1987) includes three conditions: (a) the color condition, in which the participant names the color of ink for a series of *x*s; (b) the word condition, in which the participant reads a series of words that are printed in black; and (c) the color–word condition, in which the participant names the color of ink with which an incongruent word is printed (e.g., the word *RED* printed in green ink). Forty-five sec were given to the participant for naming the items of each condition. The number of items named for the color condition is used to estimate speed of processing. The number of items completed in the color and word conditions were used to estimate the predicted color–word score. The Stroop-interference score is calculated by using the actual color–word score minus the predicted color–word score. Because speed of color naming and word reading are deducted in the estimation of amount of interference, difference in the Stroop interference score is unlikely confounded by possible group difference in these lower level abilities.

The validity of the Stroop test as a measure of selective attention has been established in numerous research examining the effect of interference caused by an irrelevant stimulus attribute (i.e., the word attribute of the color–word for the color naming task; for a review, see Macleod, 1991). The Stroop task was also found to be specifically related to the measures for selective attention (e.g., Sky Search) in a study that examined the validity of different attentional measures for children (Manly et al., 1999).

Contingency Naming Test. The CNT (Taylor et al., 1990) is presented in paper format that consists of a series of outlines of different shapes (i.e., outside shape: circle, triangle, and square) that are filled up with different colors (i.e., blue, yellow, and pink). An outline of another smaller independent shape (i.e., inside shape: circle, triangle, and square) is also embedded inside each of the outside shapes. A backward arrow is randomly presented above some of these colored shapes. The four subtests of the CNT include (a) Subtest 1—the color condition, in which the participant names the color of ink that filled up a series of shapes; (b) Subtest 2—the shape condition, in which the participant names the series of shapes (i.e., outside shape); (c) Subtest 3—the switch condition, in which the participant names the color of the ink that filled up the individual shape if the inside shape matches with the outside shape, but names the outside shape if the inside shape is different from the outside shape; and (d) the Subtest 4—the backward switch condition, in which the participant has to follow the same switching rule for Subtest 3 when there is no backward arrow above the individual colored shape. The participant has to perform a backward switch (i.e., name the color instead of the shape or vice versa) if a backward arrow is presented above the individual colored shape. The naming latency for Subtest 1 is used to estimate speed of processing. The naming latency and error rate for Subtest 3 and 4 minus the average of the corresponding value for Subtest 1 and 2 are used to estimate the time and error costs of switching. Because speed of simply performing the naming task are estimated by performances in Subtests 1 and 2, this lower level ability is subtracted in the estimation of costs of switching; thus, difference in the costs of switching would not be confounded by this variable.

The specificity of CNT in measuring cognitive flexibility or switching attention has been established in recent research for children (Anderson, 2000). This study also found that CNT is not confounded by reading ability.

Digit Span. The Digit Span subtest from the WISC–III (Wechsler, 1991) includes the following two conditions: (a) Digit Span Forward, in which the participant repeats the series of numbers spoken by the examiner; and (b) Digit Span Backward, in which the participant repeats the series of numbers spoken by the examiner in a backward way. The number of digits that the participant is able to repeat correctly is used to estimate the capacity of attention.

The validity of Digit Span as a measure of attentional capacity for verbal information has been examined and confirmed in previous studies (Mirsky, 1996; Mirsky et al., 1991; Wechsler, 1991). Because previous research suggests that analysis based on the combined score of Digit Span Forward and Digit Span Backward may lead to loss of information (for a review, see Lezak, 1995), the two scores are treated as independent variables in the present data analysis.

Tower of London. The TOL (Anderson et al., 1996; Shallice, 1982) consists of a wooden panel with three posts of different lengths erected on it and three colored balls. For each item, the participant is presented with the "tower" in standard configuration and is then required to rearrange the three colored balls on the posts so that the new configuration corresponds to the pattern presented on a stimulus card. This must be accomplished in a prescribed number of moves, which is noted at the bottom of the stimulus card. The time allowed for solving each pattern is limited to 60 sec.

Because the TOL is employed for estimating the ability of planning and problem solving, it is the most general or nonspecific test for examining executive function in the present study. This is because the ability to plan and solve problems efficiently requires the integration of a number of interrelated skills (e.g., selective and sustained attention, recognition, generation, and implementation of plans and strategies for the attainment of these goals). According to a previous validation study of the TOL for children, three measures that could be extracted from the test are able to estimate two different aspects of executive function (Anderson et al., 1996). The total number of failed attempts and total planning time for completing 12 items are used to estimate impulsivity or the ability of behavioral inhibition. In other words, greater number of failed attempts and less planning time as compared to the control are indications of impulsivity. The total score, which is derived from the time and number of attempts needed for successful completion, is used as a general measure of planning and problem-solving skills (Anderson et al., 1996).

According to Shallice (1982), the TOL is a specific measure of planning and problem-solving abilities, with lower order cognitive skills required for performance being relatively unimportant. This claim is supported because there is an observed lack of association between performances on the TOL and other measures of lower order cognitive function. Shallice also reported that lower order skills required to perform the TOL (e.g., visuo-motor coordination, spatial processing, and short-term memory) have little impact on performance. Therefore, the TOL may have fewer problems associated with more multidetermined assessment measures for executive function, and performances may be more readily interpreted in isolation from lower level abilities.

The validity of the TOL as a measure of executive functioning was also confirmed in a previous study that found that performances on the TOL are related to performances on other recognized measures of executive function (Anderson et al., 1996), including the Controlled Word Association Test (Gaddes & Crockett, 1975), the Trail Making Test (Reitan, 1958), the Rey-Osterreith Complex Figure (Osterreith, 1944; Waber & Holmes, 1985), and the Rey Auditory–Verbal Learning Test (Rey, 1964).

DATA ANALYSIS AND RESULTS

Prior to analysis, the data for dependent variables (DVs) were examined through various Statistical Package for Social Sciences programs (SPSS) for accuracy of data entry, missing values, and fit between their distributions and the assumptions of multivariate analysis. To reduce skewness, a square root transformation was performed for CNT Subtest 4 error cost. Moreover, the data for the code score was reflected, followed by a square root transformation. All subsequent analyses were based on the transformed data.

Because there are significant group difference in IQ, the data obtained were submitted to multivariate analyses of covariance (MANCOVA), with IQ as the covariate. Two MANCOVAs were performed for two groups of DVs independently: three measures for speed of processing and twelve components of executive functioning, respectively. Method 1 adjustment offered by the SPSS, which is a regression approach, was used to adjust for unequal n. Results of evaluation of assumptions of normality, homogeneity of variance–covariance matrices, linearity, and multicollinearity were satisfactory. Covariate was judged to be adequately reliable for covariance analysis.

To investigate group difference for individual variables, univariate F tests were used. A Bonferroni-type adjustment is made for inflated Type I error. Results from univariate F tests for individual variables are presented in Tables 4 and 5. To examine the mulitdimensional nature of the measures used in the study, standard

TABLE 4
Neuropsychological Measures for Speed of Processing by Group

	Control (1)		*ADHD–LD (2)*		*ADHD+LD (3)*				*Contrasts*
	M	*SD*	*M*	*SD*	*M*	*SD*	*F (2, 108)*	*ES*	*p = .05*
Stroop color score	56.55	11.67	48.94	9.42	43.32	13.40	7.93*	.12	1 > 2, 3
CNT–time for completing subtest 1	18.89	4.22	23.39	6.87	27.84	8.24	10.37**	.16	1 < 2 < 3
Sky Search time per target for Motor Control subtest	1.00	.35	1.17	.51	1.37	.85	2.20	.03	*ns*

Note. ES = effect size; CNT = Contingency Naming Test; *ns* = group contrast is not applicable as $p > .05$.
*$p < .01$. **$p < .001$.

Pearson product–moment correlation was also used to examine the relationships between various measures.

Effect of ADHD and the Comorbidity of LD on Speed of Processing

As presented in Table 3, there are three measures extracted from the battery of neuropsychological tests for measuring speed of processing. The result of MANCOVA indicates significant group difference in the combined DVs for speed of processing, *Wilks'* = .63, $F(6, 212) = 3.49$, $p < .01$, *effect size* (*ES*) = .09. Results of univariate *F* tests found that significant group difference was identified in the color score, $F(2, 108) = 7.93$, $p < .01$, *ES* = .12, and CNT-Time 1, $F(2, 108) = 10.37$, $p < .001$, *ES* = .16. For Sky Search Motor Control, group difference did not reach statistical significance.

Post hoc tests revealed that the color score for the control group was significantly higher than those for the ADHD–LD ($p < .01$) and ADHD+LD ($p < .001$) groups. For CNT-Time 1, post hoc tests revealed that the CNT-Time 1 for the Control group was significantly lower than those for the ADHD–LD ($p < .05$) and ADHD+LD ($p < .001$) groups. The CNT-Time 1 for the ADHD–LD group was also significantly lower than that for the ADHD+LD group ($p < .05$).

The results on the color score and CNT-Time 1 supported the hypothesis regarding the deficit associated with ADHD in speed of processing for verbal responses. The hypothesis was not supported by the result on Sky Search Motor Control, which reflects speed of processing in visuo-motor aspects. The additional deficit associated with the comorbidity of LD in speed of processing was identified in the result on CNT-Time 1.

TABLE 5
Neuropsychological Measures for Various Aspects of Executive Functions

	Control (1)		*ADHD–LD (2)*		*ADHD+LD (3)*				*Contrasts*
	M	*SD*	*M*	*SD*	*M*	*SD*	*F (2, 108)*	*ES*	*p = .05*
Measures for selective attention									
Sky Search Attention score	3.52	1.13	3.82	1.22	4.50	1.57	3.78*	.06	1 < 3
Stroop interference score	3.13	5.04	.40	5.18	1.69	6.89	2.86	.05	*ns*
Measures for switching attention									
CNT subtest 3 time cost	33.39	8.35	34.38	14.17	38.94	15.83	1.23	.02	*ns*
CNT subtest 3 error cost	.25	.59	.71	1.38	1.02	1.34	1.54	.02	*ns*
CNT subtest 4 time cost	52.81	16.79	53.97	19.99	61.86	25.79	1.49	.02	*ns*
CNT subtest 4 error cost[a]	.81	.78	1.58	1.23	1.54	1.21	2.15[a]	.03	*ns*
Measures for sustained attention									
Code Score[b]	1.73	.58	2.42	.98	2.88	.94	8.87**	.14	1 < 2, 3
Measures for attentional capacity									
Digit Span Forward	8.79	2.17	7.96	1.93	6.92	2.01	4.40*	.07	1 > 3
Digit Span Backward	5.24	1.66	4.56	1.54	4.00	1.60	3.00	.05	*ns*
Measures for impulsiveness									
TOL: number of failed attempts	8.62	4.47	8.36	3.16	7.48	3.40	.67	.01	*ns*
TOL: total planning time	58.06	36.16	53.81	17.15	54.32	19.23	.93	.01	*ns*
Measures for planning and problem solving									
TOL: total score	72.55	8.59	71.13	8.12	72.00	10.00	.06	<.01	*ns*

Note. ES = effect size; CNT = Contingency Naming Test; TOL = Tower of London; *ns* = group contrast is not applicable as $p > .05$.
[a]Results are reported based on a square root transformation of raw data. [b]Results are reported based on a reflected and square root transformation of raw data.
$^{*}p < .05$. $^{**}p < .001$.

Effect of ADHD and the Comorbidity of LD on Various Components of Executive Control

The result of MANCOVA indicates significant group difference in the combined DVs of executive functioning, *Wilks'* = .67, $F(24, 194) = 1.74$, $p < .05$, $ES = .17$. Results of univariate F tests found that significant group difference was identified in the Code score, $F(2, 108) = 8.87$, $p < .001$, $ES = .14$, Sky Search Attention score, $F(2, 108) = 3.78$, $p < .05$, $ES = .06$, and Digit Span Forward, $F(2, 108) = 4.40$, $p < .05$, $ES = .07$.

Post hoc tests revealed that the transformed code score for the control group was significantly lower than those for the ADHD–LD ($p < .01$) and ADHD+LD ($p < .001$) groups. According to these results, the deficit associated with ADHD in sustained attention was identified. The additional deficit associated with the comorbidity of LD was not supported.

For the Sky Search Attention score, post hoc tests revealed that the attention score for the control group was significantly lower than that for the ADHD+LD group ($p < .05$). For the Digit Span Forward score, post hoc tests revealed that the score for the control group was significantly higher than that for the ADHD+LD group ($p < .01$). Based on these results, the deficits in selective attention and attentional capacity observed for children with ADHD was due to the presence of LD. No other significant group difference was identified for all the other measures of executive control. These include switching attention, impulsiveness, and planning and problem solving.

Relationship Among Measures

To examine the multidimensional nature of the measures, the correlations among measures used for estimating a specific aspect of cognitive functioning and those for the others were compared.

The three measures for speed of processing were moderately to highly correlated (rs = .42–75). The correlations among these measures and all other measures were low to moderate (rs = .00–.55). For selective attention, the correlation between the two measures was low ($r = –.02$). The correlations between these two measures and all other measures used in the study were low to moderate (rs = .01–.45). For switching attention, the correlations between the two time measures was moderately high ($r = .61$), whereas the correlations between the two error measures was moderate ($r = .28$). The correlations among these four measures with all other measures used were low to moderate (rs = .02–.48). The correlations between code total correct score for estimating sustained attention with all other measures were low to moderate (rs = .05–.55). The correlation between the two measures of attentional capacity was moderate ($r = .46$), whereas the correlations with all other measures were low to moderate (*r*s = .00–.57). For the two measures of impulsivity, they were moderately correlated among themselves (*r* = .32). The correlation coefficients between these two measures with all other measures, except the measure for planning and problem solving, which are derived from the same test, were low (*r*s = .00–.13). For the only measure for planning and problem solving, its correlation with all other measures were low to moderate (*r*s = .04 to .43).

Because the correlation coefficients among most of the measures were low to moderate, the present result indicates that the various measures used are measuring different but related variables, thus, consistent with the conceptualization of executive functioning as a multifaceted construct.

DISCUSSION

These findings suggest that ADHD may be associated with deficits in speed of processing for verbal response and sustained attention. The comorbidity of LD was found to be specifically associated with the deficits in selective attention and attentional capacity. The results are discussed in terms of their implications on the specific deficits associated with ADHD and the theoretical models for ADHD. Alternative explanations and limitations of the study are also discussed.

Specific Deficits Associated With ADHD

A specific deficit associated with ADHD was found in two out of three measures for speed of processing. The inconsistent results are probably related to the different types of response demanded by different measures. The two measures in which the deficit in speed of processing were identified (i.e., Stroop Color and Word Test and Contingent Naming Test) require subjects to respond verbally, whereas motor response was required for the Sky Search test. This is consistent with the correlation coefficients found among the three measures, as the correlations between the two verbal measures were higher (*r* = .75) than with the motor measure (*r*s = .42–.55).

There are a few possible explanations for the result. First, this result may not necessarily reflect that ADHD is associated with slower reaction times in all verbal tasks, but it is LD that is responsible for this result. This is because rapid naming ability is related to reading ability, which is used to define LD in this study. Thus, LD, rather than ADHD, should be the significant factor that determined naming latency. However, this explanation is not consistent with the entire result because the ADHD+LD group is not the only group that has slow performance in this study. Instead, both the ADHD–LD and ADHD+LD groups have slower RT in the two verbal tasks. Because the ADHD–LD children are not affected by difficulty in reading ability, their slow performance is unlikely related to a specific deficit in rapid naming, but probably a deficit in speed of processing for a verbal task. On the other hand, the significantly longer RT for the ADHD+LD group in CNT-Time 1 may reflect the additional deficit in rapid naming associated with LD.

The resistance to interference theory developed by Dempster and colleagues (Dempster, 1993; Dempster & Corkill, 1999) may also help to explain the inconsistent results between the verbal and motor tasks. According to this theory, it is possible that three different forms of response—motor, perceptual, and verbal—each with its own developmental trajectory, can be affected differently by a specific factor. Therefore, these results may indicate that ADHD is related to a deficit in speed of processing for verbal responses, but not necessarily for motor responses.

Another possible explanation is that the Motor Control Time score of the Sky Search test is not sensitive enough for detecting group difference in the present study. This also explains the inconsistency between this result and findings in many studies that investigated the effects of specific task manipulations, where ADHD children were found to have overall slower RTs (for a review see Douglas, 1999).

Among the remaining components tested by neuropsychological test measures, children with ADHD were found to have specific deficit only in the measure for sustained attention. The comorbidity of LD was found to be associated with deficits in selective attention (measured by the Sky Search test), and attentional capacity (measured by Digit Span Forward). No specific deficit associated with ADHD or LD was identified in switching attention, impulsiveness, or planning and problem solving.

These findings, which were different from previous ones that had identified general deficits in executive functioning associated with ADHD, may raise suspicious on the present ADHD sample and diagnostic criteria. If the ADHD sample belongs to a less severe form of ADHD or is made up of the predominantly inattentive subtype, this would significantly affect the generalizability of the result for the hyperactive-impulsive and combined subtypes of ADHD. However, as shown in Tables 1 and 2, this is not the case for this ADHD sample. In fact, this ADHD sample was mostly made up of ADHD children. The screening criteria adopted also rule out the possibility that the present ADHD sample belongs to a less severe form. In this study, the source of referral for ADHD children is a tertiary pediatric hospital clinic, which is expected to see cases of a more severe nature. Moreover, the ADHD participants are initially diagnosed according to *DSM–IV* criteria prior to referral to the study and are further screened by the BASC–PRS.

The inconsistent findings between this study and previous ones that suggest that ADHD is associated with a general deficit in executive functioning point to the importance of isolating two factors in the evaluation of specific deficits in executive functioning associated with ADHD. First, because ADHD is associated with a slower speed of processing, it is essential to isolate the specific deficit in this "lower" level ability when the "higher" level executive functions are examined. It is also essential to isolate the specific effects associated with the comorbidity of LD when the deficits specific to ADHD are studied. Therefore, previous findings did not isolate the effects associated with these two factors in their examination, and suggested that ADHD is associated with a general deficit in executive control are questioned.

The difference in conceptualization of executive functioning may also contribute to the inconsistent conclusions between this study and previous ones that suggest that ADHD is associated with a general deficit in executive control. In previous studies that defined executive control according to the catch-all concept, (for a review, see Barkley et al., 1992), deficit identified by a single measure may be considered as evidence of executive dysfunctioning. However, in this study, children with ADHD are expected to have problems in various components of executive control if ADHD is associated with a general deficit in executive functioning. If deficit is identified only for a specific task, it is considered as a specific deficit, which is not the same as a general deficit in executive control.

These findings that indicate ADHD children are slower and not more impulsive than controls versus the common observation of impulsive behavior related to ADHD in natural settings also support the observation that it is essential to differentiate cognitive deficits examined in laboratory settings from behavioral problems observed in natural settings (Shaywitz, Fletcher, & Shaywitz, 1995). As pointed out by Shaywitz et al. (1995), whereas laboratory measures are usually specifically defined, measures in natural settings are usually less specific behavioral descriptions. Thus, the lack of consistency between the two measures may reflect the different meanings of terminology used for measures in laboratory and natural settings.

In short, this result suggests that it is important to examine the comorbidity of LD for clinical diagnosis and treatment of children with ADHD. It is also meaningful to conceptualize executive functioning in terms of specific components rather than a catch-all concept when applied for clinical evaluation of a specific disorder. The discrepancy between measures in laboratory and natural settings also indicate that the problems observed in natural settings for ADHD children may not necessarily mean that they have the "real" cognitive deficit as defined by laboratory measures.

Implications on the Theoretical Models for ADHD

According to the executive dysfunction model developed by Barkley (1994, 1997, 1999), the direct and cascade effects of inhibitory deficit may account for all the phenomena seen in ADHD children. However, there are a number of hurdles for the executive dysfunction model to work through before the hypothesis that ADHD is purely an inhibitory or executive deficit can be confirmed:

1. Given that impairment in various executive control strategies is the major manifestation of inhibitory dysfunction, it is important to use specific measurement to evaluate these control strategies for ADHD children. However, the effect mirrored in a single measure may contain a variety of interactive executive effects. Thus, it is difficult to separate executive processes from each other for evaluating deficits related to ADHD.

2. To test the hypothesis of executive dysfunction for ADHD, it is equally important to distinguish executive from subordinate processes. However, according to Logan, Schachar, and Tannock (2000), there are still no commonly accepted methods for distinguishing them. Moreover, there is no current theory that provides a complete account of subordinate and executive processes. Without specific definitions and measurements for these control processes, the hypothesised executive dysfunction of ADHD children would be too nonspecific.

In this study, an attempt has been made to isolate and measure various aspects of executive control by using a battery of neuropsychological test measures. Moreover, most of the ADHD children recruited in the study belong to the *DSM–IV* combined subtype. However, results in this study question the validity of the executive dysfunction model, which emphasises the manifestation of deficit in executive control strategies for ADHD with hyperactivity. First, ADHD was not found to be associated with deficit in almost all the measures that pertained to measure executive control processes in this study. Second, the inhibition and executive dysfunction models, which describe fast and impulsive responses for ADHD children, have great difficulty in explaining their slow speed of processing tapped in this study. Although the deficit in sustained attention identified for ADHD may be captured by the catch-all concept of executive dysfunctioning, the theory is inconsistent with the negative findings for all other measures of specific executive components.

The resource allocation model for ADHD appears to be more promising for explaining the findings of this study (Sergeant & Meere, 1990a, 1990b; Sergeant et al., 1999). First, the slower performance of ADHD children can be attributed to a deficit in the regulation of effort, activation, or both. According to Meere (1996), high event rates tax arousal and lead to inaccurate performance (e.g., commission error), whereas low event rates tax activation and lead to slow responding (e.g., omission error). The energetic pool modulates both systems, and poor regulation of this pool can result in increased errors and slow responses. The deficit in sustaining attention on a single task found in this study (i.e., higher omission error in Code Transmission, a task with a low event rate) also provides added support for this allocation or regulatory deficit hypothesis. This is because sustaining attention on a single task actually mirrors the operation of the allocation or regulation of effort and activation across trials over time. If there is a regulatory deficit of effort, activation, or both, it is expected to find deficiency in a task that tapped into the ability to sustain attention. In other words, a deficit in sustained attention does not mean a functional attentional deficit, but reflects a failure to utilize intact attentional capabilities.

Limitations of This Study and Directions for Future Research

Although this study has attempted to utilize specific measures and strict screening procedures for the sample, there are also limitations that may affect the generalizability of the result.

This finding, which is inconsistent with research utilizing the stop signal paradigm (for reviews see Logan et al., 2000; Oosterlaan & Sergeant, 1998), suggests that the "behavioral inhibition" examined by the stop signal task may be different from the measure of impulsivity examined in this research. The estimation of impulsivity by the TOL used in this study may also be limited by the nature of the evaluated task, which is less specific than the stop signal task as a measure of stopping a particular response. However, the results of an extended study participated by the same participants of this study, which utilized experimental measures of the task–set switching paradigm and stop signal paradigm consistently indicate that ADHD is not associated with deficits in inhibitory control (Wu et al., 2002b). In these experiments, the ongoing tasks involved color naming and word reading of Stroop color–word stimuli. Participants have to switch between doing the two tasks on every two consecutive trials. Inhibitory control was reflected by probability and reaction time of successful stops in the stop signal switch and nonswitch trials for the two tasks. Findings indicate that children with ADHD have slower and less accurate responses for the go trials, but deficits in inhibitory control were not identified. ADHD was also not associated with deficits in task switching, as reflected in the comparison for the probability and reaction time of successful stops between the switch and nonswitch conditions. Thus, results from both neuropsychological test and experimental measures for participants of this study converged to reveal that ADHD is not associated with deficits in inhibitory or executive control. Instead, ADHD is related to a specific deficit in regulation for attentional resources, which affects the stability of performance for the go-task. Nevertheless, though the result of this study utilizing neuropsychological test measures converged with the experimental measures used for the same participants, replications of the study with different populations would be needed for it to weight against the findings that support an inhibitory control deficit associated with ADHD. On the other hand, studies using measures of inhibitory control for specific domains (e.g., covert visuospatial attention) would also help to shed light on the factor and specific domain involved in the identification of specific deficit associated with ADHD (McDonald, Bennett, Chambers, & Castiello, 1999).

The inconsistent findings among measures that aim at examining the same variable also reflect that some measures may not be as specific as they are meant to be. For example, the Stroop interference score may be confounded by reading ability; thus, it is not as specific as the Sky Search Attention score. Similarly, Digit Span Backward may be confounded by the ability of holding and manipulating information simultaneously; thus, it is not as pure as Digit Span Forward for measuring attentional capacity.

In this study, the multifaceted construct of executive functioning and the validity of various neuropsychological measures chosen for examining the specified components (see Table 3) are based on previous findings (e.g., Manly et al., 1999; Mirsky, 1996; Posner & Raichle, 1994). The correlations among different measures suggest that most of the measures pertaining to estimate a specific functioning was moderately correlated, whereas the correlations among measures for different aspects were low to moderate. Though the result of this study is consistent with the conceptualtization of executive functioning as a multifaceted construct, there is still no explicit analysis of the measurement attributes of the test measures used in this study due to the limited number of participants involved. Further research utilizing statistical techniques like the Structural Equation Model to examine the multifaceted model of attention or executive function, and measurement attributes of specific measures, would probably help to clarify the catch-all conceptualization of executive control. This may also help to resolve the conceptual and measurement problem identified by Logan and his colleagues (2000); (i.e., the differentiation between executive from subordinate processes). Future research for the analysis of measurement attributes may also benefit from the use of functional magnetic resonance imaging (fMRI) and clinical population with focal lesion.

Another limitation of this study is the lack of a pure LD group. To offer more definite answers for the specific effect associated with LD, it is necessary to compare the performance of several groups of participants, including children who exhibit pure symptoms of LD, ADHD, as well as the comorbid and control groups. Only with such multigroup designs, is it then possible to distinguish the effects that are unique to ADHD, LD, and the comorbidity of the two disorders.

Finally, this study has not directly investigated the contributing effect of situational variables on the deficits associated with ADHD, and this may have contributed to the small effect size of group difference found in this study. However, these findings suggest that ADHD is associated with state regulation deficit, rather than real limitations of attentional or executive capabilities. Even if poor performance of ADHD children in attentional capabilities has been found in previous studies, these results found that such poor performance is not unavoidable. Therefore, this means that situational variables, which could significantly affect one's motivation or alertness, could play an important role in the manifestation of "deficits" in ADHD. In this study, which used a strict and structural situation to tap cognitive variables, no deficit in attentional capabilities was found. However, in the classroom or other less structural environments, behavioral problems may be observed that can affect a child's utilization of attentional capabilities.

The significant effect of situational variables for ADHD has also been emphasized by the multifactor model of ADHD (Sanson, Smart, Prior, & Oberklaid, 1993). According to this model, multiple situational variables interact and create a high-risk situation for the development of behavioral difficulties related to ADHD. Thus, the cause of ADHD does not lie in a single factor. It is worthwhile to investigate the interaction between situational variables and specific measures of executive control in future research.

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