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Stop Signal and Conners' Continuous Performance Tasks

Test–Retest Reliability of Two Inhibition Measures in ADHD Children

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Objective: To measure test -retest reliability of the Stop-Signal Task (SST) and the Conners' Continuous Performance Test (CPT) in children with ADHD. **Methods:** 12 children with ADHD (age 11.46 ±1.66) participated in the study. Primary outcome measures were stop-signal reaction time (SSRT) for the SST and CPT's commission errors (%FP). For each participant, we acquired three morning (8:00am) measurements and behavioral observations, separated by two 7-day intervals. Reliability of cognitive measures and behavioral observations was measured using the Intraclass-correlation coefficient (ICC). **Results:** ICC values for SSRT and %FP were 0.72. Consistency of behavioral observations was much lower (ICC =0.41). **Conclusion:** Both the SST and the CPT yielded reliable measurements in ADHD children. Our findings lend further support to using these measures in the study of ADHD. *(J. of Att. Dis. 2009; 13(2) 137-143)*

Keywords: *reliability; inhibition; ADHD*

ADHD is a common and impairing neuropsychiatric disorder of childhood affecting approximately 3% to 5% of school-age children in the general population (Szatmari, Offord, & Boyle, 1989) and 50% of children who are referred for clinic assessment (Offord, Boyle, & Jones, 1987). ADHD is defined by developmentally inappropriate and impairing levels of inattentiveness, impulsiveness, and hyperactivity.

Current views of ADHD focus on the central role of cognitive deficits. Indeed, both motivational and executive control functions have been proposed as independent, complementary underlying cognitive processes that may be associated with ADHD (Quay, 1997; Sagvolden, Johansen, Aase, & Russell, 2005; Schachar & Tannock, 1995; Schachar, Tannock, Marriott, & Logan, 1995; Sonuga-Barke, 2002, 2003). A particular executive function, inhibitory control, occupies a central role in current theories of ADHD (Barkley, 1997a, 1997b; Quay, 1997; Schachar et al., 1995; Schachar & Tannock, 1995). Inhibitory control is a fundamental executive control process which comes into play in situations requiring withholding, switching, or suddenly interrupting ongoing actions and thoughts. Deficient inhibitory control is a well-replicated finding in children with ADHD with several meta-analyses supporting the overall findings in the literature (Oosterlaan, Logan, & Sergeant, 1998; Schachar, Mota, Logan, Tannock, & Klim, 2000; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005).

The two most commonly used laboratory measures of inhibitory control used in research involving ADHD populations are the Stop Signal Task (SST) and the Continuous Performance Test (CPT). The SST had been described in

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detail by Logan (Logan, 1994). In contrast, many CPT versions exist with crucial differences among them. For that reason, Conners' standardized and normed a version of the CPT which is now widely used (Conners, 2004).

The SST and the Conners' CPT are similar in that both invoke demand for inhibitory control by presenting concurrent go and stop tasks. The primary or go task involves a reaction time task which participants perform as quickly and as accurately as they can. The primary or go task sets up the prepotent response in both the CPT and the SST. The demand for inhibitory control is invoked by presenting, randomly and infrequently, a signal to stop the ongoing response to the go signal. Whether or not the participant is able to stop this prepotent response on a particular trial is considered the essential index of inhibitory control.

The SST and the CPT differ in several important ways. The reaction time task in the Conners' CPT involves a series of letters. Each of these letters requires a response, and the response is the same in each case except when the participant sees the letter "X." In the SST, the go signal is either an X or an O, and the response depends on the stimulus; for example, an X requires a right hand response and an O requires a left hand response. The "stop signal" also differs in the tasks. The stop signal in the CPT, an X, is presented in the same modality as the go signals (appearing as a letter on the screen). In the SST, the stop signal is presented in a different modality, that is, a tone presented by headphones. When the stop signal in the SST is presented, the participant is instructed to stop the ongoing response whether it is an X or an O. Therefore, in the SST, the go task but not the stop signal involves choice, whereas in the CPT, the stop signal but not the go task involves choice.

Another crucial difference between the SST and CPT is the timing of the presentation of the stop signal. In the CPT, there is never a delay between the presentations of the stop signal; that is, the stop signal (the letter "X") always appears at the same time as a go signal (any other letter). In the SST, there is always a delay between the presentation of the go signal and the presentation of the stop signal. Therefore, the cognitive processes invoked by the two inhibition tasks are quite different. An appropriate strategy in the CPT is to withhold or restrain one's responses to the go stimulus to determine whether a stop signal (i.e., the letter "X") will appear. In the SST, the stop signal invokes a withdrawal or cancellation process because it always follows the go signal by some delay. It would be possible to delay one's responses in the SST past the presentation of the go stimulus to check for the presentation of a subsequent stop signal. However, the SST overcomes this possibility by using a dynamic tracking algorithm to manipulate the delay of the stop signal. If a participant is able to stop a particular response, the stop delay between the presentation of the go and of the stop signals is increased on the subsequent stop-signal trial making it more difficult to inhibit. If the participant imposes a delay as a conscious strategy to increase the probability of inhibition, the tracking algorithm ensures that the delay increases to the point at which, on an average, 50% of trials with a stop signal will be correctly inhibited. The tracking algorithm nullifies the effectiveness of any delaying strategy and ensures that the SST measures cancellation rather than restraint.

The differences between the SST and the Conners' CPT translate into differences in type of outcome measure generated by each. The primary index of inhibitory control in the CPT is commission or false positive errors. In the context of the CPT, a false positive is the failure to stop a response to a stop signal trial (i.e., pressing when there is a letter "X"). By contrast, omission errors in the CPT, are go-task targets that are not correctly detected (not pressing for any other letter). The number of omission errors and their latency are thought to reflect vigilance (Conners, 2004; Willcutt et al., 2005). The main index of inhibitory control in the SST is not the ability to inhibit but rather the latency of the inhibition process, known as stop signal reaction time (SSRT). SSRT is the difference between the mean reaction time (RT) of no-signal trials and the delay at which 50% of signal-inhibit trials are correctly stopped. SSRT is a measure of the latency of the internally generated stopping process that is triggered by the presentation of a stop signal.

Numerous studies support the discriminate validity of SST and CPT in ADHD. Both the CPT and the SST performed well in a recent meta-analysis of 83 studies of various executive control measures, which compared ADHD and control individuals. The weighted mean effect size was .61 for the SST and .51 for false positives in the CPT. Of the 27 studies comparing ADHD and control participants on the SST, 22 showed a statistically significant difference. Of the 28 studies comparing ADHD and controls on the CPT, 17 showed statistically significant differences (Willcutt et al., 2005). Individuals with a diagnosis of ADHD make more errors of omission on the CPT (mean effect size = .64; 23/30 studies positive; Willcutt et al., 2005). There is also more specific evidence that supports the discriminate validity of the SST and the CPT for children with ADHD. For example, a recent meta-analysis (Nichols & Waschbusch, 2004) had concluded that CPT was able to "consistently discriminate" children with ADHD from normal controls. Similarly, another meta-analysis (Oosterlaan et al., 1998) showed that SST differentiated between children with

ADHD and normal controls on the SST (however, no significant differences were found between ADHD and conduct disorder groups).

By contrast to evidence of discriminant validity, much less is known about the reliability of these measures in ADHD. Test–retest reliability can be defined broadly as the degree of agreement when presenting the same task to the same participant twice or more (Rousson, Gasser, & Seifert, 2002). Establishing acceptable reliability for a test is considered by many to be a necessary (though not sufficient) precondition for its validity (Cook & Beckman, 2006). Test–retest reliability was the highest rated test criterion among surveyed experts in a recent NIH consensus symposium concerning neuropsychological tests for assessment of schizophrenia (Green et al., 2004). Test–retest reliability translates directly into statistical power: As reliability decreases for any given measure, a larger sample size is required to detect the same amount of change (Green et al., 2004).

The few existing reliability studies of the SST and the Conners' CPT are limited in various ways that could affect the validity and generality of their results. First, reliability estimates are dependant on specific populations (Cook & Beckman, 2006). However, most existing SST and CPT reliability studies examined either healthy participants or patient groups other than those with ADHD (Kuntsi, Andreou, Ma, Borger, & van der Meere, 2005). Second, most reliability studies of the CPT have used versions other than Conners' CPT. Finally, the results of test–retest reliability studies may be affected by possible time of day effects on cognitive performance (Ben-Pazi, Gross-Tsur, Bergman, & Shalev, 2003; Kim, Dueker, Hasher, & Goldstein, 2002; Winocur & Hasher, 2004).

Given the contrast between importance of inhibitory control measures to current ADHD research and theory and the limited availability of reliability data, the goal of the current study was to measure test–retest reliability of SST and the Conners' CPT in medication-free children with ADHD. Because current ADHD theories suggest a link between behavioral symptoms and inhibition deficits in this disorder (Barkley, 1998), we also assessed levels of ADHD behaviors during tasks performance. Finally, because different times of day may have significant effects on cognitive performance (Kim et al., 2002; Winocur & Hasher, 2004) all testing was performed at the same time of day (8.00 a.m.) and an identical between-session interval (1 week). Reliability of measures was evaluated using the Intraclass Correlation Coefficient (ICC). The ICC denotes the ratio of between-subject variability to the sum of subject variability and measurement error (Streiner & Norman, 1995). We hypothesized that both SST and CPT would show acceptable (ICC > 0.6) reliability values (McGraw & Wong, 1996).

Methods

Participants

ADHD participants were drawn from a clinic for children with attention and behavior problems. The sample was similar in socioeconomic status and ethnicity to that of the community from which it was drawn. ADHD diagnosis was confirmed by one of two child psychiatrists using the K-SADS, a structured clinical interview (Kaufman et al., 1997). To be included in the study, children had to meet *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.; American Psychiatric Association, 1994) criteria for ADHD (at least 6 of 9 inattentive, 6 of 9 hyperactive-impulsive symptoms, or both and evidence of at least moderate impairment in two settings). Participants were excluded if they had an IQ below 80 on both verbal and performance scales of the WISC-III, a history of pervasive developmental disorder, psychosis, obsessive compulsive disorder, Tourette's syndrome, serious current medical problem, substance abuse, loss of consciousness, or concurrent treatment with medication other than a stimulant. The current study was part of a larger placebo control trial involving methylphenidate. As part of the larger study, children arrived unmedicated at the clinic at 8.00 a.m. to do baseline measures including those reported in this study. At 9.00 a.m., they were given methylphenidate or a placebo and continue to stay in the clinic until the end of the day with intermittent assessment using a variety of measures.

The protocol was approved by the Research Ethics Board and written informed consent and assent were obtained.

Procedure

Participants arrived at the clinic in the morning and remained there until testing was completed. Each of the three testing sessions was performed during the same day of the week and at the same time of day (8.00 a.m.). All children were unmedicated for at least 24 hr prior to testing. The plasma half-life of methylphenidate is reported to be 3 hr (Greenhill et al., 2002).

Following SST and CPT administration, the child's restlessness, inattentiveness, and compliance over the previous hour of testing was documented by an observer with extensive clinical experience with assessing ADHD children using the Inattention/Overactivity With Aggression Conners' Rating Scale (IOWA; Loney & Milich, 1982).

Measures

Stop Signal Task (SST). The SST involved two concurrent tasks. The go task was a choice reaction time task (discriminating an X from an O presented on a computer screen) which participants performed as quickly and as accurately as possible. On 25% of SST go task trials selected at random, a 1000 Hz tone emitted from the computer signaled participants to withhold their response on that trial (i.e., a stop signal). The delay between the onset of the go and SST was manipulated in 50 ms steps to converge on the delay at which individuals were able to stop 50% of the time. The task involved 128 trials of which 32 involved stop signals and 96 did not. The go task stimulus was presented for 1000 ms immediately following a fixation point of 500 ms. The stop tone was presented by headphones at a comfortable listening level.

We estimated the latency of the unobserved inhibition process (SSRT) by subtracting mean delay (at which the participant inhibited 50% of the time) from mean go reaction time. Calculated in this way, SSRT provides an estimate of the inhibitory control processes (Logan, 1994) and is the primary outcome measure of the SST. We also report the reliability of the go task reaction time (Go RT) and the standard deviation of Go RT (Go SD).

Conners' Continuous Performance Test (CPT). The Conners' CPT consisted of 360 letters that appeared on the screen one at a time in 18 consecutive blocks of 20 trials. Participants were required to press the space bar when any letter other than letter "X" appeared on the screen. Letter "X" appeared on 10% of trials. The primary index of inhibition in the CPT is the percentage of commission errors (false positives) defined as the number of times the person incorrectly responded to an X (% FP). Vigilance is indexed by percentage of omission errors (% OMM), hit rate reaction time (HR RT) and standard error of hit rate reaction time (HR SE). Omission errors are targets to which the person did not respond (Conners, 2004).

Behavioral rating scale. The Inattention/Overactivity With Aggression (IOWA) Conners' Rating Scale (Loney & Milich, 1982) was used as the measure of behavior in children during the 1 hr that was required for the testing. The rating scale consists of two subscales, Inattention/Overactivity and Oppositional/Defiance, each with five items. Each item is rated on a 4-point scale from 0 (*not at all*) to 3 (*very much*). Scores for the two scales were summed. Higher scores indicated more ADHD and disruptive behaviors. The scale has been validated (Atkins, Pelham, & Licht, 1989; Pelham & Waschbusch, 2004), has been shown to have sound psychometric properties (Waschbusch & Willoughby, 2007), and is sensitive to treatment effects (Pelham et al., 2001).

Statistical Analyses

Statistical analysis was performed using SPSS software. Group means and standard deviations were calculated for each measure at each of the three occasions. Reliability was evaluated by the intraclass correlation coefficient (ICC) using a mixed random effects model of absolute agreement (Shrout & Fleiss, 1979). An absolute agreement model considers column variance (i.e., the 3 fixed measurement points) by taking total score variance as its denominator. Thus, when measurements differ in absolute value (regardless of the reason), they are viewed as disagreements (McGraw & Wong, 1996).

To assess between-sessions variations in behavioral symptoms, an ICC model of consistency was used. Thus, high IOWA ICC values could suggest nonsignificant differences between the three testing sessions. For each of the three testing sessions, correlations between inhibitory control measures (SSRT and % FP) and between all cognitive measures and behavioral symptoms were calculated using Pearson's correlations. For both absolute agreement and consistency models, an acceptable reliability was determined as (ICC > 0.6; McGraw & Wong, 1996).

Results

The age range of our participants was 9 to 15 years with a mean of 11.5 ± 1.7 years. The sample consisted of 11 boys and one girl (Table 1).

Group mean values of serial measurements on cognitive and behavioral measures. Table 2 presents mean values for consecutive CPT, SST, and IOWA measurements.

Test–retest reliability of cognitive measures. Reliability analyses (Table 3) showed acceptable reliability for SSRT (ICC = 0.72), Go RT (ICC = 0.62), and Go SD (ICC = 0.74) in the SST. Commission errors (% FP), HR RT, HR SE in the Conners' CPT showed acceptable reliability, but reliability of omission errors (% OMM) was low, nearing zero (ICC = 0.092).

Within-session correlations of inhibitory control measures. No significant correlations ($p < .05$) were found between SSRT and % FP for either testing session.

Behavioral observations. Low ICC values were measured for between-sessions IOWA ratings (Table 3). In addition, correlations between IOWA and either SST or CPT performance were generally not significant (Table 4).

Table 1
Sample Characteristics

	Mean ± SD	Median
Age		
Years	11.46 ± 1.66	11.25
SST		
SSRT	353.55 ± 153.59	353.97
Go RT	669.23 ± 186.06	700.82
Go SD	231.2 ± 91.01	240.55
CPT		
% OMM	22.61 ± 12.51	23.33
% FP	23.79 ± 6.61	25
HR RT	405.85 ± 96.97	388.58
HR SE	14.47 ± 5.74	13.41
IOWA		
Total score	1.97 ± 1.15	2.17

Note: SST = stop-signal task; SSRT = stop signal reaction time; Go RT = go task reaction time; Go SD = standard deviation of Go RT; CPT = Conners' Continuous Performance Test; OMM = omission errors; FP = false positive (commission errors); HR RT = CPT hit rate reaction time; HR SE = CPT hit rate standard error; IOWA = total score.

Table 2
Means of Serial Measurements

	Measurement 1	Measurement 2	Measurement 3
SST			
SSRT	313.33 ± 210.69	240.62 ± 102.18	304.53 ± 242.84
Go RT	638.05 ± 145.76	688.15 ± 145.76	681.50 ± 212.63
Go SD	224.35 ± 92.34	246.17 ± 97.32	251.14 ± 109.50
CPT			
% OMM	13 ± 11.39	22.67 ± 24.41	32.17 ± 20.86
% FP	22.83 ± 6.70	22.75 ± 7.88	25.75 ± 7.17
HR RT	384.9 ± 75.16	420.64 ± 123.49	411.99 ± 111.88
HR SE	13.08 ± 5.56	14.62 ± 7.84	15.73 ± 6.14
IOWA	1.25 ± 1.14	2.25 ± 1.29	2.42 ± 1.782

Note: See note to Table 1; Measurement Time 1, 2, 3 = mean group values according to time of administration.

Discussion

Cognitive theories of ADHD suggest that inhibitory control deficits are central to the disorder. Two inhibitory control measures, the SST and the Conners' CPT, have been widely used in recent ADHD studies. To support the conclusion that there is an IC deficit in ADHD, the current study is the first to compare the reliability of these two inhibitory control measures in a sample of rigorously diagnosed unmedicated children with ADHD. In assessing reliability of these measures, we carefully controlled for possible nonrandom time of day effects on cognitive performance by testing all participants at the same time of day.

Table 3
ICC Values of SST, CPT, and IOWA Measures

Task	Statistic	ICC	*F* value
SST	SSRT	0.72[a]	9.08
	Go RT	0.62[a]	5.61
	Go SD	0.74[a]	9.67
CPT	% OMM	0.09[a]	1.36
	% FP	0.72[a]	9.54
	HR RT	0.76[a]	10.84
	HR SE	0.63[a]	6.28
IOWA	Total score	0.41[b]	3.76

Note: See note to Table 1; ICC = values of intraclass correlation coefficients.
a. absolute agreement model.
b. consistency model.

Table 4
Within Session Correlations of SST and CPT and Behavioral Measures

Test	IOWA Time 1	IOWA Time 2	IOWA Time 3
SST			
SSRT Time 1	–.0361 $p < .248$		
SSRT Time 2		–.290 $p = .0360$	
SSRT Time 3			–.113 $p = .728$
CPT			
% FP Time 1	.316 $p = .317$		
% FP Time 2		–.361 $p = .249$	
% FP Time 3			–.325 $p = .302$
HR SE Time 1	–.172 $p = .593$		
HR SE Time 2		–.141 $p = .661$	
HR SE Time 3			.437 $p = .0155$

Note: See note to Table 1; SSRT Time 1, 2, 3 = stop signal reaction time from SST for measurement times 1, 2, and 3, respectively. Numbers denote the order of each test.

The main finding of the study was that both tasks yielded a reliable measure of inhibitory control (SSRT from the SST; % FP from the Conners' CPT; Barkley, 1998; Logan, Schachar, & Tannock, 1997). These results add evidence of reliability to existing findings of discriminant validity of these two tasks in the study of ADHD. The reliability and validity data adds weight to the conclusion that inhibitory control is an important characteristic of ADHD.

The indices of inhibitory control from the SST and Conners' CPT were stable despite marked intersession differences in behavior as evident in low ICC for the IOWA ratings. These findings suggest inhibitory control performance in ADHD children is independent of their overt behavior. The current result accords with other studies in which moderate correlation between total ADHD symptoms scores and inhibitory control have been reported (Schachar et al., 2005; Solanto et al., 2001). Thus, our findings suggest that inhibitory control, as assessed by either the SST or the Conners' CPT, is state-independent, thereby supporting findings of existing studies that used those measures in children with ADHD.

Although both the SSRT and % FP have shown acceptable reliability estimates, no significant correlations were found between these measures for each testing session. The lack of significant correlations may be accountable by the fact that the two tasks measure different things. The main index of inhibitory control in the SST is the latency of the inhibition process (i.e., the SSRT) rather than the ability to inhibit. It is thus plausible that the SST and the CPT can each provide reliable and useful measurements of different aspects of inhibitory control processes. Indeed, the current finding that restraint as measured by the CPT and cancellation as measured by the SST are not significantly correlated accords with results of other recent clinical and neuroimaging findings.

In addition to reliable inhibitory control measures, both SST and CPT had yielded acceptably high reliability estimates of reaction times (GO RT and HR RT, respectively) and for variability of reaction time (GO SD and HR SE, respectively). The reaction time component of both tasks is often considered as a measure of vigilance (Bearden, Cassisi, & White, 2004). In contrast, we found very poor reliability of omission errors in the CPT. Indeed, the use of omission errors as a measure of inattentiveness has already been criticized by Conners (2004) as neglecting response latency and variability. For example, slow responses to targets can cause both omission and commission errors on a particular trial.

Interpretation of our findings is limited by two main factors. First, the focus on a rigorously defined age and diagnosis group limits the generalization of our findings. Indeed, that reliability may differ between populations is implicating a tradeoff between generalizability of findings and diagnostic accuracy. However, existing SST and CPT studies did not measure reliability in medication free, pediatric ADHD populations. Thus, although many studies reported SST and CPT findings in pediatric ADHD, the lack of group-specific reliability data justifies the focus of the present study. A second limitation of the present study is the relatively small sample size. Given the small sample size, our results should be viewed as preliminary. Future studies of SSRT and CPT reliability should employ larger sample size and address ADHD diagnostic subgroups. With the above limitations in mind, results of the current experiment have implications for theories of inhibitory control in particular and executive functions in general. Although the low and nonsignificant association between SST and CPT inhibitory control measures should be viewed with caution given the small sample size, it may be in accordance with other studies that suggest that these aspects of inhibition depend on both distinct and overlapping neural circuitry.

In summary, we found that inhibitory control could be measured reliably in unmedicated children with ADHD using either the SST or the CPT even in the face of marked behavioral changes. Thus, our findings lend further support to the adequacy of using the SST and the CPT in the study of ADHD. They do not, however, speak to the issue of diagnostic accuracy and the clinical decisions that are sometimes made using these measures.

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