Acta Med. Okayama, 2012
Vol. 66, No. 5, pp. 377-386

Acta Medica
Okayama
http://escholarship.lib.okayama-u.ac.jp/amo/

Original Article

Relationships between the Color-Word Matching Stroop Task and the Go/NoGo Task: Toward Multifaceted Assessment of Attention and Inhibition Abilities of Children

Teruko Morooka[a]*, Tatsuya Ogino[b], Akihito Takeuchi[a], Kaoru Hanafusa[a], Makio Oka[a], and Yoko Ohtsuka[a]

[a]*Department of Child Neurology, Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences, Okayama 700-8558, Japan,* [b]*Department of Children Studies, Faculty of Children Studies, Chugokugakuen University, Okayama 701-0197, Japan*

Both selective attention and response inhibition can be assessed through the Stroop task and the Go/NoGo task (Go/NoGo). The color-word matching Stroop task (cwmStroop) differs from the traditional Stroop task in ways that make it easy to administer, and it enables the examiners to analyze reaction time. It is expected that the cwmStroop and Go/NoGo tasks will be useful as clinical assessments for children with developmental disorders and in combination with functional magnetic resonance imaging studies. The objectives of this study were to elucidate the pattern of developmental change in cwmStroop scores and Go/NoGo scores and to determine whether and how cwmStroop scores are related to Go/NoGo scores. The subjects consisted of 108 healthy Japanese children aged 6-14 years. We found that cwmStroop and Go/NoGo scores displayed clear developmental changes between 6 and 14 years of age. The children's scores on the 2 tasks followed different developmental courses, however, and the correlation between scores on the two tasks was weak on the whole. These results indicate that the cwmStroop and Go/NoGo tasks tap different aspects of selective attention and response inhibition. Therefore it is expected that the combination of both tests will be useful in the multifaceted assessment of selective attention and response inhibition in childhood.

Key words: color-word matching Stroop task, Go/NoGo task, selective attention, response inhibition

Attention is a fundamental domain of brain function involving multiple aspects of cognitive ability, and is purported to consist of divided, sustained, and selective attention [1]. Selective attention, the ability to focus on a specific stimulus or activity among various other forms of input [2], plays an important role in behaving appropriately. Response inhibition, the ability to actively suppress or delay an inappropriate behavior [3, 4], is likewise an essential cognitive domain for our daily life. Both selective attention and response inhibition can be assessed through the Stroop task [1, 5].

Since the publication of Stroop's seminal work [6], many versions of the Stroop task have been formulated, differing in the number of stimuli, the colors and stimulus words employed, and even the nature of the stimuli (*e.g.*, figures instead of words or colors). In most versions of the Stroop task, however, subjects are asked to read aloud the printed names of four colors. For studies using functional magnetic reso-

Received January 10, 2012; accepted March 12, 2012.
*Corresponding author. Phone: +81-86-223-7151; Fax: +81-86-235-7636
E-mail: gmd20022@s.okayama-u.ac.jp (T. Morooka)

nance imaging (fMRI), a computer-assisted Stroop task has also been developed in which subjects are required to respond by pressing buttons [7]. In this version of the task, in order for the subject to consistently select the intended button out of the 4 available, practice rounds are needed before real trials.

The color-word matching Stroop task (cwmStroop) by Schroeter [8] differs from the traditional Stroop task. It is a forced-choice task in which the subject must decide whether the color of the top row of letters corresponds to the color name written on the bottom row, and 3 conditions, described in detail below, are presented randomly. The cwmStroop is easy to administer because subjects are only required to select either yes or no, and it is very useful because it enables examiners to analyze reaction times. These attributes of the cwmStroop make it suitable for both clinical assessment and fMRI studies. Several imaging studies using fMRI or functional near-infrared spectroscopy (fNIRS) have shown that brain activation relating to Stroop interference increases with age in the dorsolateral prefrontal cortex in the cwmStroop as well as the traditional Stroop task [8, 9]. Activation in the anterior cingulate cortex has been invariably observed in the traditional Stroop task, though not in the cwmStroop [9, 10].

To date, however, no constructive concept and developmental change in performance on the cwmStroop in healthy children has been proposed.

The Go/NoGo task (Go/NoGo) is another method of measuring selective attention and response inhibition [11, 12]. In the Go/NoGo, subjects are requested to respond when any stimulus appears (the Go stimulus) on a screen except when a certain stimulus appears (the NoGo stimuli).

It is expected that the cwmStroop and Go/NoGo will be useful in the assessment of the attention and inhibition abilities of children with developmental disorders such as pervasive developmental disorders (PDD) and attention deficit/hyperactivity disorder (AD/HD).

Some previous studies of the use of traditional Stroop and Go/NoGo tasks in children have reported that the AD/HD group showed significant cognitive dysfunction, including more errors [13, 14], longer reaction times and greater variability of reaction time [15, 16] compared to the control group. Although studies on developmental disorders using cwmStroop are rare, Jourdan Moser *et al.* [17] reported that boys with AD/HD showed right dorsolateral prefrontal activation on functional MRI that was not observed in control subjects during an incongruent trial of cwmStroop.

In order to apply the cwmStroop and Go/NoGo in clinical practice or in research on developmental disorders, we need to elucidate normative data, their developmental change and the relationship between the 2 tasks. In previous studies, weak positive correlations have been identified between the interference effect on the traditional Stroop task and reaction time (RT) on the Go/NoGo [11, 18], though this correlation has not yet been confirmed between the cwmStroop and the Go/NoGo.

The goals of this study are as follows: (1) to elucidate the pattern of developmental change in cwmStroop scores and Go/NoGo scores, and (2) to determine whether and how the cwmStroop scores are related to the Go/NoGo scores.

Materials and Methods

Subjects. The subjects consisted of 108 healthy children, all Japanese, aged 6–14 years (average age 10.2 ± 2.4; 64 boys and 44 girls; 89 right-handed and 19 left-handed), who agreed to participate in this investigation in response to a request made through the employees of our hospital and neighboring hospitals, and through the parents' associations of local elementary and junior high schools. All subjects were first graders at elementary schools or older, and had acquired reading ability by the time of this study. Generally, most healthy Japanese children acquire the ability to read Hiragana letters (Japanese phonograms) before age 6 [19].

Parents completed the High-Functioning Autism Spectrum Screening Questionnaire (ASSQ) [20, 21] and the AD/HD Rating Scale (AD/HD-RS) [22]. In addition, parents were asked to respond to another questionnaire that included questions about the children's medical, prenatal, and developmental histories, as well as their visual and hearing acuity.

Children with definite developmental retardation or a medical history of neurological disorders or visual disorders that disturbed their daily lives were excluded. As a result, of the 133 children examined, 108 children were included in the final analysis. We received written informed consent from the parents of all participants and presented small gifts (book coupons) to the subjects after the test.

The subjects were classified into 3 age groups: Group A (range 6–8 y; 25 boys and 12 girls, total 37), Group B (range 9–11 y; 25 boys and 22 girls, total 47) and Group C (range 12–14 y; 14 boys and 10 girls, total 24).

Procedures. The following 2 tasks were administered to all subjects. Both tasks were programmed with E-Prime^R 1.0 (Psychology Software Tools, Inc.) and implemented on a laptop computer with a 12-inch touch-screen LCD flat panel (Lenovo Thinkpad^R × 60 tablet). The subjects' responses were obtained by Serial Response Box (SRBOX) adjunct to E-prime.

All tasks were administered in a quiet room, with the subjects seated in a chair and the PC and SRBOX placed in front of the subjects and within their reach. All subjects could perform the tasks without assistance from their parents, who were in a separate room. The cwmStroop and Go/NoGo task took about 10 min each. Fig. 1 shows the processes of the 2 tasks.

The cwmStroop task (Fig. 2). The cwmStroop task was administered according to Schroeter *et al.* [8]. Two rows of letters appeared on the screen, and subjects were instructed to decide whether the color of the top row letters corresponded to the color name written with black ink in the bottom row. The color names that appeared in the bottom row consisted of "あか[aka] (red)", "みどり[midori] (green)", "あお[ao] (blue)" and "きいろ[kiiro] (yellow)". Subjects were requested to press a button, either '1' (YES-response) or '2' (NO-response), on the SRBOX as quickly as possible.

Three conditions were possible. In the neutral condition, the letters in the top row were 'XXX' displayed in red, green, blue or yellow. In the congruent condition, the top row contained one of the color words "あか[aka] (red)", "みどり[midori] (green)", "あお[ao] (blue)" and "きいろ[kiiro] (yellow)" printed in the congruent color. In the incongruent condition, the top row contained one of the color words "あか[aka] (red)", "みどり[midori] (green)", "あお[ao] (blue)" and "きいろ[kiiro] (yellow)" printed in a different color to produce interference between the color word and color name. To shift the subject's visual attention to the top row initially, the word on the bottom row was presented 100 ms later. Words remained on the screen until a response was given, with a maximum time of 4 sec. Four blocks, each consisting of 30 stimuli (10 congruent stimuli, 10 neutral stimuli, and 10 incongruent stimuli), were executed, with 30-second breaks between blocks. All of the color words excluding 'XXX' were written in Hiragana (Japanese phonograms). For practice, the subjects were asked to give answers aloud in the first 6 trials, and then were asked to press buttons in the following 10 trials. In the practice session, the subjects were informed whether their responses were right or wrong. We verified that all participants including 6-year-olds understood the rules for this task and could read and comprehend color names.

The Go/NoGo task (Fig. 3). The Go/NoGo task was administered according to Booth *et al.* [12] with some modifications. Three kinds of pictures appeared on the screen in random order. One picture was the No Go stimulus, and the other 2 were Go stimuli. Subjects were requested to press a button as quickly as possible when a Go stimulus appeared, but to take no action when the No Go stimulus appeared.

Each stimulus was presented for 500 ms, and only the responses within 500 ms were included in the analysis. The inter-stimulus-interval varied randomly among 1,000, 1,500, and 2,000 ms. The average stimulus onset asynchrony was 1,500 ms. Three blocks, each consisting of 100 stimuli (85 Go stimuli and 15 No Go stimuli), were executed, with 10-second breaks between blocks. The set of 3 pictures was different in each block. In the practice session, which consisted of 3 trials, the subjects were informed whether their responses were right or wrong. Thereafter, the subject performed 10 trials without feedback. We confirmed that all participants understood the rules for this task.

Statistical analysis. As representative scores on the cwmStroop task, we used the rate of correct answers in all trials (%Correct), mean reaction time (mRT), standard deviation of reaction time (SDRT), and the difference between the incongruent and neutral conditions in terms of %Correct (N-I%Cor) and mRT (I-NRT). Only scores in the incongruent and neutral conditions were evaluated, and those in congruent condition were not analyzed. Contrasting incongruent with neutral trials yields a measure for Stroop interference [8]. Although the contrast between incongru-

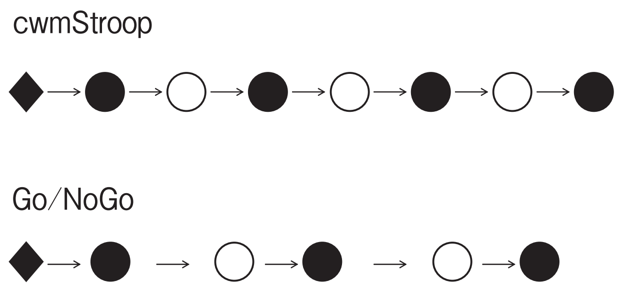

Fig. 1 The processes in the cwmStroop and the Go/NoGo tasks. black rhombuses represent practice, black circles represent tests, and white circles represent breaks.

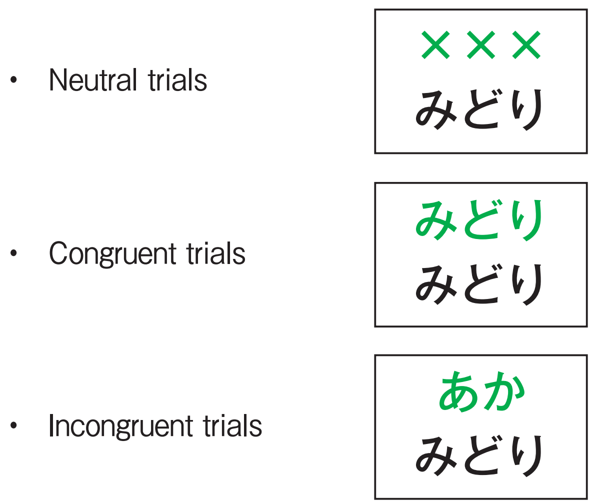

Fig. 2 Example trials of the color-word matching Stroop task. From the top, stimulus for a congruent trial, an incongruent trial, and a neutral trial are presented. The letter strings written in Hiragana "みどり[midori]" and "あか[aka]" mean green and red respectively. In all cases, the subject is required is to push button '1' (Yes response) at the time of the correct response.

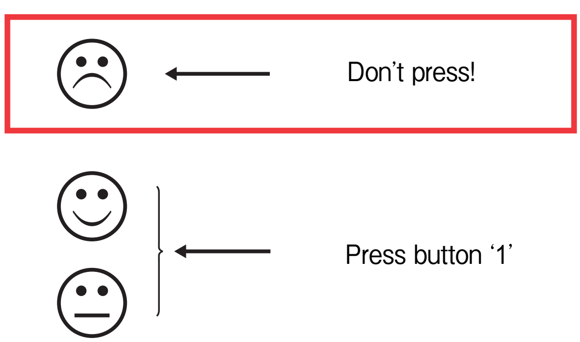

Fig. 3 Examples of No Go stimuli and a Go stimulus used in the Go/NoGo task. The details of the testing procedure are provided in the text.

ent and congruent trials also contains interference processes, a facilitation effect also influences the results [8].

As representative scores of the Go/NoGo task, we used the No-Go error rate (%Commission), Go error rate (%Omission), mean reaction time for Go stimuli (CorrectRT), and standard deviation of reaction time (CorrectRTSD).

Behavioral data were analyzed with repeated measures ANOVA or one-way factorial ANOVA. For multiple comparisons, we applied the *t*-test with Bonferroni correction. The gender effect was analyzed using Student's *t*-test. The partial correlation coefficients between the 8 cwmStroop scores and the 4 Go/No Go scores were calculated with age as the control variable. All statistical analyses were performed using SPSS 12.0 for Windows. We selected $p < 0.05$ as the threshold of significance.

This study was approved by the Ethics Committee on Epidemiological Studies of Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences.

Results

Table 1 provides the means and standard deviations of the performance measures in the cwmStroop and the Go/NoGo tasks.

The cwmStroop task (Table 2). The % Correct, mRT and SDRT data were analyzed with repeated measures ANOVA, with task condition (neutral vs. incongruent) as a within-subjects factor and age group (A vs. B vs. C) as a between-subjects factor.

Regarding %Correct, there were significant main effects of task condition ($F_{1,105} = 150$, $p < 0.001$) and age ($F_{2,105} = 21.5$, $p < 0.001$). In addition, the interaction between task condition and age was significant ($F_{2,105} = 9.4$, $p < 0.001$). Post hoc tests revealed higher %Correct in the neutral condition than in the incongruent condition in groups A, B and C ($p < 0.001$). Subjects in groups B and C responded correctly significantly more often than those in Group A in both the incongruent and neutral conditions ($p < 0.001$ except for $p < 0.01$ in the comparison of Groups A and B in the neutral condition).

As for mRT, there were significant main effects of task condition ($F_{1,105} = 292.6$, $p < 0.001$) and age ($F_{2,105} = 77.4$, $p < 0.001$). The interaction between

Table 1 The means and standard deviations of performance measures in the cwmStroop and the Go/NoGo task

Task	Measure	Group A (6–8 years) Means (SD)	Group B (9–11 years) Means (SD)	Group C (12–14 years) Means (SD)
cwmStroop	In%	72.9 (14.8)	85.0 (10.5)	89.5 (8.2)
	Ne%	92.5 (5.4)	96.1 (3.8)	98.4 (3.2)
	InRT (ms)	1938.7 (355.0)	1386.9 (298.7)	1046.9 (243.7)
	NeRT (ms)	1548.9 (296.5)	1085.4 (205.0)	841.2 (143.1)
	InRTSD (ms)	676.5 (159.7)	495.6 (151.9)	316.5 (127.5)
	NeRTSD (ms)	554.8 (153.3)	379.5 (145.2)	229.5 (99.5)
	N-I%Cor	19.6 (13.5)	11.1 (9.9)	8.8 (6.9)
	I-NRT (ms)	389.7 (222.3)	301.5 (146.4)	205.6 (138.6)
Go/NoGo	%Commission	29.6 (18.2)	29.8 (15.4)	25.7 (14.8)
	%Omission	47.7 (21.9)	25.6 (19.0)	10.1 (10.4)
	Correct RT (ms)	411.2 (24.9)	392.7 (31.3)	372.0 (28.5)
	Correct RTSD (ms)	55.7 (11.9)	57.3 (9.4)	54.0 (7.1)

Table 2 Group comparisons in cwmStroop performance

	age	condition	interaction
%Correct	A<B***, A<C***	In<Ne***	each condition: A<B (In***, Ne**), A<C*** each age group: In<Ne***
mRT	A>B>C***	In>Ne***	each conditon: A>B>C*** each age group: In>Ne***
SDRT	A>B>C***	In>Ne***	ns
N-I%Cor	A>B*, A>C* (one way factorial ANOVA)		
I-NRT	A>C* (one way factorial ANOVA)		

*$p<0.05$, **$p<0.01$, ***$p<0.001$, ns, not significant ($p>0.05$); In, Incongruent; Ne, Neutral.

task condition and age was also significant ($F_{2,105}=8.2$, $p=0.001$). Post hoc tests revealed a longer reaction time in the incongruent condition than in the neutral condition in groups A, B and C ($p<0.001$). Reaction times were shorter in older subject groups in both the incongruent and neutral conditions (A > B > C, $p<0.001$).

As for SDRT, there were significant main effects of task condition ($F_{1,105}=76.1$, $p<0.001$) and age ($F_{2,105}=51.4$, $p<0.001$). In this case, however, the interaction between task condition and age was not significant ($F_{2,105}=0.6$, $p>0.05$). Post hoc tests revealed larger variation in reaction time in the incongruent condition than in the neutral condition in all age groups ($p<0.001$). In addition, older age groups exhibited less variation in reaction time than younger groups did (A > B > C, $p<0.001$).

To examine differences among the age groups, one-way factorial ANOVA was conducted on the N-I%Cor and I-NRT scores. This test revealed a significant main effect of age on both scores. Post hoc tests revealed a smaller difference between the incongruent and neutral conditions in older age groups (%Correct: A > B, A > C, $p<0.05$, RT: A > C, $p<0.05$).

Using Student's *t*-test to compare the cwmStroop scores between males and females in each age group, we found a significant gender difference in group A. In group A, the males gave correct responses significantly more frequently than the females in the incongruent condition ($p < 0.05$).

The Go/NoGo task (Table 3). The error rate on the Go/NoGo task was analyzed by means of repeated measures ANOVA, with condition (%Commission vs. %Omission) as a within-subjects factor and age group (A vs. B vs. C) as a between-subjects factor. There was a significant main effect of age ($F_{2,105} = 52.8$, $p < 0.001$) but not of condition. In addition, the interaction between condition and age was significant ($F_{2,105} = 9.5$, $p < 0.001$). Post hoc tests revealed a lower error rate in older age groups in %Omission (A > B > C, $p < 0.01$), but no influence of age in %Commission ($p > 0.05$). Further, %Omission was higher than %Commission in Group A ($p = 0.001$). In contrast, %Commission was higher than %Omission in Group C ($p < 0.05$). Although %Commission did not appear to improve with age, the frequency of %Omission was higher in the younger age groups and declined with age.

Correct RT and RTSD were compared between the age groups by means of one-way factorial ANOVA. There was a significant main effect of age on reaction time, and post hoc tests revealed a shorter reaction time in older age groups (A > B > C, $p < 0.05$; A > C, $p < 0.001$). As for RTSD, there was no influence of age ($p > 0.05$).

Using Student's *t*-test to compare the Go/NoGo scores between males and females in each age group, two significant gender differences were found in group B. In group B, the males made fewer omission errors and showed significantly shorter reaction times in their correct responses than the females ($p < 0.05$). In addition, the males exhibited greater variation in reaction time than the females ($p < 0.05$).

The relationship between the cwmStroop and the Go/NoGo task (Table 4). All of the partial correlation coefficients between the cwmStroop scores and the Go/NoGo scores with age as a control variable are shown in Table 3. Six of the 8 score categories on the cwmStroop showed weak correlations ($0.4 > |r| \geq 0.2$) with at least one score category on the

Table 3 Group comparisons in Go/NoGo task performance

	age	condition	interaction
Error rate	A>B>C***	ns	%Commission: ns %Omission: A>B>C** A: Commission<Omission** B: ns C: Commission>Omission*
CorrectRT	A>B>C*, A>C*** (one way factorial ANOVA)		
CorrectRTSD	ns (one way factorial ANOVA)		

*$p<0.05$, **$p<0.01$, ***$p<0.001$, ns: not significant ($p>0.05$).

Table 4 Partial correlation coefficients between scores on the cwmStroop and the Go/NoGo task

	Go/NoGo (r)			
cwmStroop	%Commission	%Omission	Correct RT	Correct RTSD
In%Correct	−0.20*	0.08	0.21*	−0.16
Ne%Correct	−0.26**	0.06	0.19	−0.08
InRT	−0.23**	0.27**	0.27**	−0.13
NeRT	−0.13	0.26**	0.21*	−0.14
InRTSD	−0.02	0.08	0.13	0.04
NeRTSD	0.21*	−0.09	−0.11	0.21*
I-NRT	−0.22*	0.12	0.18*	−0.05
N-I%Cor	0.12	−0.07	−0.15	0.14

*$p<0.05$, **$p<0.01$, In, Incongruent; Ne, Neutral.

Go/NoGo.

%Correct in the incongruent condition on the cwmStroop showed a weak positive correlation with Correct RT (r = 0.21, $p < 0.05$) and a weak negative correlation with %Commission (r = −0.20, $p < 0.05$) on the Go/NoGo. %Correct in the neutral condition on the cwmStroop was negatively correlated with %Commission on the Go/NoGo (r = −0.26, $p < 0.01$).

RT in the incongruent condition on the cwmStroop showed weak positive correlations with %Omission (r = 0.27, $p < 0.01$) and Correct RT (r = 0.27, $p < 0.01$), and a weak negative correlation with %Commission (r = −0.23, $p < 0.01$), on the Go/NoGo. RT in the neutral condition on the cwmStroop was positively correlated with %Omission (r = 0.26, $p < 0.01$) and Correct RT (r = 0.21, $p < 0.05$) on the Go/NoGo.

RTSD in the neutral condition on the cwmStroop showed a weak positive correlation with %Commission (r = 0.21, $p < 0.05$) and Correct RTSD (r = 0.21, $p < 0.05$) on the Go/NoGo.

I-N RT on the cwmStroop showed a weak negative correlation with %Commission on the Go/NoGo (r = −0.22, $p < 0.05$).

Discussion

Our study revealed that cwmStroop and Go/NoGo scores showed clear developmental changes between 6 and 14 years of age. Specifically, the rate of correct response increases and the mean reaction time decreases with age on both tasks. In addition, the interference effects of correct rate (N-I%Cor) and reaction time (I-NRT) on the cwmStroop were largest in the youngest group and decreased with age. Although no previous studies have reported on developmental changes in cwmStroop scores during childhood, Schroeter *et al.* [8] have compared cwmStroop scores in children (7–13 years old) with those in adults (19–29 years old). They found that age had no effect on the rate of correct response, but RT and I-NRT were significantly shorter in adults than in children. Therefore, RT and I-NRT, at least, seem to show developmental change after childhood. Concerning the Go/NoGo task, Johnstone *et al.* [23] have reported that rate of correct response to Go stimuli increased and correct RT decreased with age between 7 and 12 years; this result is compatible with those of our study.

In addition to clear patterns of developmental change in cwmStroop and Go/NoGo scores, we found a difference between the age groups in the rate of improvement in performance on the 2 tasks. A significant difference in the correct response rate in the cwmStroop was detected between Groups A and B, but not between Groups B and C in either the incongruent or the neutral condition. These observations indicate that the correct response rate in the cwmStroop shows more obvious developmental change at younger ages. Furthermore, N-I%Cor was significantly different between Groups A and B but not between Groups B and C. Considering the above-mentioned report showing that the difference in correct response rates on the cwmStroop between children and adults was not significant [8], the correct response rate on the cwmStroop might show clear developmental change in early childhood and little change after adolescence. On the other hand, %Omission on the Go/NoGo continued to decline steadily from 6 to 14 years of age, and %Commission was not influenced by age; these findings are compatible with those of the study by Johnstone *et al.* [23].

There was also a difference between the 2 tasks in terms of developmental change in RTSD. Whereas RTSD on the cwmStroop continued to decline with age, RTSD on the Go/NoGo was not influenced by age. The implication is that variation in RT might depend on task complexity. Given that the interaction between condition and age was not significant, and that similar developmental changes with age were observed in both the incongruent and neutral conditions, developmental change in RTSD on the cwmStroop does not seem to reflect interference control ability, though this is considered to be the major construct of the Stroop task.

The interactions between condition and age observed in %Correct and RT on the cwmStroop were confusing. Our analysis of simple main effects showed similar developmental changes in both the incongruent and neutral conditions, which cannot explain the observed interactions. The only other thing that might be pertinent to these interactions is the variation in the significance of the difference in %Correct between groups A and B in each condition. The p value was smaller in the incongruent condition than in the neutral condition, indicating a clearer difference between groups A and B in the incongruent condition. There could also be a similar disparity in the extent of the difference in RT among the groups between the 2 conditions, although the current analysis could not determine whether this was the case.

Since the developmental change in the scores on the cwmStroop was different from that in the scores on the Go/NoGo, the psychological process tapped by the cwmStroop may be different from that tapped by the Go/NoGo. Therefore, we calculated partial correlation coefficients between score categories for the 2 tasks to directly elucidate the relationship between the 2 tasks. We found correlations between several score categories. The Go/NoGo score category that correlated with the most cwmStroop score categories was %Commission. It is thought that %Commission on the Go/NoGo reflects the ability to inhibit predominant response [24]. Therefore, the inhibition of predominant response may also play some role in the cwmStroop.

In addition to %Commission, several scores showed correlations in both tasks; namely, %Omission showed a correlation with RT on the cwmStroop, Correct RT showed a correlation with RT and correct response rate on the cwmStroop, and Correct RTSD showed a correlation with RTSD in the neutral condition on the cwmStroop. However, the correlation between cwmStroop scores and Go/NoGo scores was weak as a whole, with the absolute values of the correlation coefficients being less than 0.3.

Although we could not find any previous studies that examined the relationship between the cwmStroop and the Go/NoGo, the relationship between the traditional Stroop task (in which the subject reads the color name aloud) and the Go/NoGo task has been studied by several authors. Only weak correlations were indicated between RT on the Go/NoGo and RT of incongruent color naming on the Stroop by Barbarotto *et al.* [11], and between RT on the Go/NoGo and the difference in RT between the incongruent and neutral conditions on the Stroop by Lamm *et al.* [18]. Based on these results and ours, the Stroop and the Go/NoGo might have only a few commonalities, primarily assessing quite different psychological processes.

To clarify the differences and common points between the cognitive functions measured by these tasks, imaging and behavioral data might be useful. In fact, several imaging studies have provided some clues to clarify the relationship between the 2 tasks. Studies using fMRI or fNIRS have indicated that frontal-parietal networks play an important role in selective attention and response inhibition [28, 29]. One imaging study using fNIRS [8] has shown that significant brain activation in the left lateral prefrontal cortex is elicited in healthy children aged 7-13 during the cwmStroop task, and that brain activation in the dorsolateral prefrontal cortex due to Stroop interference increases from 7 to 29 years of age in correlation with behavioral performance improvement.

Likewise, an fMRI study of the cwmStroop [10] has indicated that the lateral prefrontal cortex and the parietal cortex were activated in the incongruent condition as compared to the neutral condition. In addition, no substantial activation in the anterior cingulated cortex (ACC) was detected. In contrast, an earlier fMRI study using the Go/NoGo in healthy children aged 9-11 [12] showed greater bilateral activation in the posterior cingulate, thalamus and hippocampo-amygdaloid region in response to No-Go blocks (consisting of No-Go and Go stimuli) than in response to Go blocks (consisting of only Go stimuli). Furthermore, the Go/NoGo task elicited significant brain activation in the ACC [30].

The bilateral dorsolateral prefrontal cortex, which is activated during the cwmStroop, is also activated by tasks tapping verbal and visuo-spatial working memory [31, 32]. The ACC, on the other hand, which was activated by the Go/NoGo, is also activated by tasks requiring the subject to focus on a specific target [33].

Comparing the actual procedures of the 2 tasks, the Go/NoGo is simpler since subjects are required to hold only one target stimulus in mind throughout the task. This is thought to require the use of short-term memory to remember the target stimulus for a fixed period of time without active manipulation of the information. The cwmStroop, in contrast, is the more complex task, since subjects are asked to focus on novel information in each trial. This is thought to require greater engagement of central executive processes to govern the entire working memory system, unlike the Go/NoGo. From another standpoint, the Go/NoGo task might simply assess the ability to inhibit the execution of motor responses, while the cwmStroop task might assess the ability of the subject to exert inhibition or interference control in higher cognitive tasks that involve working memory or flexible set shifting.

Our results indicate that the cwmStroop and Go/NoGo tasks tap different aspects of selective attention and response inhibition, and that the scores on the 2 tasks follow different developmental courses. Therefore it is expected that both tests will be useful in the multifaceted assessment of selective attention and response inhibition in childhood. It is also expected that they will contribute to clarifying the differences in cognitive functions between AD/HD and PDD, which cause similar behavioral problems in daily life, such as inattention or impulsive behavior.

In the future, it will be necessary to elucidate the precise distribution of scores on the 2 tasks, the age at which performance is maximized, and any gender differences in performance using a larger number of subjects with a wider age range. Event-related fMRI study may also elucidate the topographical differences in brain activation between the conditions during the performance of the 2 tasks, and may reveal changes in the performance on these tasks related to development. Accordingly, extensive functional imaging studies would be useful for the precise assessment of children in clinical practice.

Acknowledgments. This work was partially supported by a Research Grant (19A-8 "Comprehensive study on making practical guidelines for developmental disorders based on neuroscientific findings") for Nervous and Mental Disorders from the Ministry of Health, Labor and Welfare.

References

1. Salo R, Henik A and Robertson LC: Interpreting Stroop Interference: An Analysis of Differences Between Task Versions. Neuropsychology (2001) 15: 462–471.
2. Whyte J: Attention and arousal: Basic science aspects. Arch Phys Med Rehabil (1992) 73: 940–949.
3. Clark JM: Contributions of inhibitory mechanisms to unified theory in neuroscience and psychology. Brain Cogn (1996) 30: 127–152.
4. Barkley RA: Behavioral inhibition, sustained attention, and executive functions: constructing a unifying theory of ADHD. Psychological Bulletin (1997) 121: 65–94.
5. Adleman NE, Menon V, Blasey CM, White CD, Warsofsky IS, Glover GH and Reiss AL: A developmental fMRI study of the Stroop color-word task. Neuroimage (2002) 16: 61–75.
6. Stroop JR: Studies of interference in serial verbal reactions. J Exp Psychol (1935) 18: 643–662.
7. Bush G, Whalen PJ, Rosen BR, Jenike MA, McInerney SC and Rauch SL: The counting stroop: An interference task specialized for functional neuroimaging—Validation study with functional MRI. Hum Brain Mapp (1998) 6: 270–282.
8. Schroeter ML, Zysset S, Wahl M and von Cramon DY: Prefrontal activation due to Stroop interference increases during development-an event-related fNIRS study. Neuroimage (2004) 23: 1317–1325.
9. MacDonald AW 3rd, Cohen JD, Stenger VA and Carter CS: Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. Science (2000) 288: 1835–1838.
10. Zysset S, Muller K, Lohmann G and von Cramon DY: Color-word matching Stroop task: separating interference and response conflict. Neuroimage (2001) 13: 29–36.
11. Barbarotto R, Laiacona M, Frosio M, Vecchio M, Farinato A and Capitani E: A normative study on visual reaction times and two Stroop colour-word tests. Ital J Neurol Sci (1998) 19: 161–170.
12. Booth JR, Burman DD, Meyer JR, Lei Z, Trommer BL, Davenport ND, Li W, Parrish TB, Gitelman DR and Mesulam MM: Neural development of selective attention and response inhibition. Neuroimage (2003) 20: 737–751.
13. Houghton S, Douglas G, West J, Whiting K, Wall M, Langsford S, Powell L and Carroll A: Differential patterns of executive function in children with attention-deficit hyperactivity disorder according to gender and subtype. J Child Neurol (1999) 14: 801–805.
14. Happe F, Booth R, Charlton R and Hughes C: Executive function deficit in autism spectrum disorders and attention-deficit/hyperactivity disorder: Examining profiles across domains and ages. Brain and Cognition (2006) 61: 25–39.
15. Leung PW and Connolly KJ: Distractibility in hyperactive and conduct-disordered children. J Child Psychol Psychiatry (1996) 37: 305–312.
16. Klein C, Wendling K, Huettner P, Ruder H and Peper M: Intra-Subject Variability in Attention-Deficit Hyperactivity Disorder. Biol Psychiatry (2006) 60: 1088–1097.
17. Jourdan Moser S, Cutini S, Weber P and Schroeter ML: Right prefrontal brain activation due to Stroop interference is altered in attention-deficit hyperactivity disorder—A functional near-infrared spectroscopy study. Psychiatry Res (2009) 173: 190–195.
18. Lamm C, Zelazo PD and Lewis MD: Neural correlates of cognitive control in childhood and adolescence: Disentangling the contributions of age and executive function. Neuropsychologia (2006) 44: 2139–2148.
19. Shimamura N and Mikami H: Acquisition of Hiragana letters by pre-school children-In Comparison with the 1967 Investigation of the National Language Research Institute-. Japanese Journal of Educational Psychology (1994) 42: 70–76 (in Japanese).
20. Ii T, Hayashi E, Hirose Y and Tojo Y: The high-functioning autism spectrum screening questionnaire; in Studies on the characteristics and educational supports of children with autisum and AD/HD, Reports of Grants-in-Aid for Scientific Research (B)(2)#13410042, The National Institute of Special Education, Tokyo (2003) pp39–45 (in Japanese).
21. Ehlers S, Gillberg C and Wing L: A screening questionnaire for Asperger syndrome and other high-functioning autism spectrum disorders in school-age children. J Autism Dev Disord (1999) 29: 129–141.
22. Dupaul GJ, Power TJ, Anastopoulos AD and Reid R: ADHD Rating Scale-IV. Checklists, norms, and clinical interpretation, Dupaul GJ ed, Gilford press, New York (1998).
23. Johnstone SJ, Dimoska A, Smith JL, Barry RJ, Pleffer CB, Chiswick D and Clarke AR: The development of stop-signal and Go/Nogo response inhibition in children aged 7–12 years: Performance and event-related potential indices. Int J Psychophysiol (2007) 63: 25–38.
24. Casey BJ, Trainor RJ, Orendi JL, Schubert AB, Nystrom LE,

Giedd JN, Castellanos FX, Haxby JV, Noll DC, Cohen JD, Forman SD, Dahl RE and Rapoport JL: A developmental functional MRI study of prefrontal activation during performance of a go-no go task. J Cogn Neurosci (1997) 9: 835-847.
25. Barkley RA: The ecological validity of laboratory and analogue assessment methods of ADHD symptoms. J Abnorm Child Psychol (1991) 19: 149-178.
26. Rueckert L and Grafman J: Sustained attention deficits in patients with right frontal lesions. Neuropsychologia (1996) 34: 953-963.
27. Ballard JC: Assessing attention: comparison of response-inhibition and traditional continuous performance tests. J Clin Exp Neuropsychol (2001) 23: 331-350.
28. Gitelman DR, Nobre AC, Parrish TB, LaBar KS, Kim YH, Meyer JR and Mesulam MM: A large-scale distributed network for covert spatial attention; further anatomical delineation based on stringent behavioral and cognitive controls. Brain (1999) 122: 1093-1106.
29. Casey BJ, Durston S and Fossella JA: Evidence for a mechanistic model of cognitive control. Clin Neurosci Res (2001) 1: 267-282.
30. Lutcke H and Frahm J: Lateralized anterior cingulated function during error processing and conflict monitoring as revealed by high-resolution fMRI. Cereb Cortex (2008) 18: 508-515.
31. D'Esposito M, Detre JA, Alsop DC, Shin RK, Atlas S and Grossman M: The neutral basis of the central executive system of working memory. Nature (1995) 378: 279-281.
32. Kwon H, Reiss AL and Menon V: Neural basis of protracted developmental changes in visuo-spatial working memory. Proc Natl Acad Sci USA (2002) 99: 13336-13341.
33. Posner MI and Raichle ME: Images of Mind, W.H. Freeman, New York (1994).

Two versions of the Stroop test are available in PEBL. The Stroop test is a classic test of attentional filtering. It is typically demonstrated as a reading versus color naming task, where reading is more automatic and thus less impacted. Located in battery/stroop/stroop.pbl and battery/stroop/vstroop.pbl. The standard PEBL stroop test compares color naming versus word naming under three response conditions (impacting what the screen looks like). These are specified in colorresp in the output data