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Developmental trends of performance on the Wisconsin Card Sorting Test in Korean children

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Although the Wisconsin Card Sorting Test (WCST) has been widely used to evaluate the frontal lobe functioning, there is no published data on normal children in Korea which results in limitation of its clinical validity in children. The present study was conducted to investigate developmental trends of normal children's performance on the WCST. The computerized version of WCST (Heaton, 1991) was administered to 160 elementary school children aged 7 to 11 years. Their Full Scale IQs measured by the Korean version of WISC-R ranged from 80 to 138 (M=111.02, SD=11.77). Children did not differ in FSIQ, VIQ, and PIQ when compared based on age. However, very moderate correlations were found between FSIQ, VIQ, and PIQ scores and the scoring variables. Out of the 10 WCST scoring variables, 9 variables except Failure to Maintain Set showed age effect, but sex difference was not found in any variables. There was also no significant interaction effect between age and sex. Important differences in developmental trends were found among the 10 WCST scoring variables. The nature of these differences was effectively explained by the three factors. From the principal axis analysis with oblique rotation using the 10 WCST scoring variables, three factors with eigenvalue greater than 1 emerged, interpreted as conceptual formation (Factor I: accounted for 60.24% of variance), perseveration (Factor II: 18.52% of variance), and ability to sustain attention (Factor III: 12.12% of variance). The growth curves for the 5 scoring variables constituting Factor I(Total Number of Corrects, Nonperseverative Errors, Conceptual Level Responses, Number of Categories Completed, and Trials to Complete First Category) showed significant improvement from age 7 to 8, suggesting a developmental spurt during that period. By contrast, Perseveration Errors included in Factor II significantly decreased from age 9 to 11, while Failure to Maintain Set included in Factor III showed no age effect. These results suggest that the WCST performance requires multiple cognitive functioning with different developmental trends.

Keywords : WCST, normal children, developmental trend, cognitive functioning.

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The Wisconsin Card Sorting Test(WCST; Grant & Berg, 1948), a frequently administered neuropsychological test, was developed to assess abstraction ability. Although its validity was first established through lesion studies, more recently functional imaging data have been used to corroborate the brain-behavior relationship. During the 1960's and 1970's, lesion studies showed that the WCST was sensitive to frontal lobe functioning(Drewe, 1974; Milner, 1963; Robinson, Heaton, Lehamn, & Stilson, 1980). During the 1980's and 1990's PET and SPEC imaging studies have confirmed the pivotal role of the frontal lobe in WCST performance by documenting activation primarily of dorsolateral prefrontal cortex during test completion (Marenco, Coppola, Daniel, Zigun, & Weinberger, 1993; Rezai, Andreasen, Alliger, Cohen, Swayze, & O;Leary, 1993; Rubin, Holm, Friberg, Videbech, Andersen, Bendsen, Stromso, Larsen, Lassen, & Hemmingsen, 1991). Studies about the cognitive and developmental effects of early frontal lobe injury among children have also sparkled considerable interest in the WCST as a potential measure of frontal lobe functioning among school-age children(Chelune, & Baer, 1986; Chelune & Thompson, 1987; Welsh, Pennington, & Groisser, 1991).

In this study we investigated normative development in the WCST performance of school-age children in order to tap the developmental course of frontal lobe functions. Myelination of the frontal lobe proceeds rapidly from the age 4 until about age 13(Reines & Goldman, 1980). Case(1992) argued that between age of 5 and 10 years, a sequence takes place in children's behavior that indicates a fundamental reorganization of their attentional and executive processes which are correlated with physiological changes in the frontal lobe of children. On the standard test on concept acquisition(Gholson & Beilin, 1979; Stevenson, 1968) which makes requirements similar to those of the WCST, 6-year-olds were reported to use their ability to classify along various dimensions to aid them in their hypothesis about which card is correct. By the age of 8, children showed the ability to shift to a totally different dimension if the first dimension selected yield an inconsistent pattern or if the rule is changed.

In three studies with school aged children(Becker, Isaac, & Hynd, 1987; Passler, Isaac, & Hynd, 1985; Welsh, 1987), investigators observed age-dependent changes in children's performance and suggested that behaviors attributed to the prefrontal lobe reveal the emergence of at least three stages of skill integration and maturation with differing developmental trajectories: at age 6, 10, and during adolescence. Some of these developmental trends can be placed in the larger context of normal cognitive development: For instance, changes in prefrontal-like skills at age 6 is consistent with what has been referred to in the field of developmental psychology as the 5 to 7 year shift(White, 1970). In a variety of content domains, investigators have documented rapid advances in systematic problems solving during this period; these advances have been attributed to increase in logical thought(Piaget, 1954), working memory(Case, 1985), and selective attention (Miller & Weisse, 1981). Given the pattern of data that was reported in the forgoing research, frontal lobe function generates a wave-like rather than a linear change(Case, 1992) which is roughly correspond to those stage-like moves to a higher level of processing postulated by Piaget(Phillips, 1969); preoperational thinking(aged 2 to 4), concrete

operation(around ages 5 to 7 untill 11), formal operation (initiated at the beginning of adolescence).

Using WCST, Chelune and Baer(1986) reported linear age effects for "Categories Achieved", "Perseveration Errors", and "Failure to Maintain Set" with 105 normal children aged 6 to 12. A dramatic improvement in performance occurred on the "Categories Achieved", "Perseveration Errors" from age 6 to 7. With a plateau occurring at age 8 their performance was indistinguishable from that of normal adults by the time children are 10 years old. However "Failure to Maintain Set" do not show the same degree of linear improvement with age as was evident with "Categories Achieved", "Perseveration Errors". It might be explained by the inherent nature of the variable. That is, in contrast to the other WCST scoring variables, a high score on this variable might not be necessarily reflect an inferior performance (Koren, Seidman, Harrison, Lyons, Kremen, Caplan, Goldstein, Faraone & Tsuang, 1998) because in order to lose set one has to acquire it first. Thus a low score on this variable might be reflective of either performance superb(i.e. perfect maintenance of set) or extremely poor performance(i.e. no set has ever been acquired). Welsh et al(1991)'s study with 379 normal children aged 3 to 12 reported that the performance of "Perseverative Responses" revealed developmental spurt from age 7 to 8 and reached adult levels by age 10, replicating the data reported by Chelune and Baer(1986). Levin, Culhan, Hartman, Evankovich, and Mattson(1991) with 52 normal children age grouped 7~8, 9~12, 13~15 reported that "Categories Completed", "Conceptual Level Responses", "Perseverative Errors", "Failure to Maintain Set" showed significant improvement by age 12.

With increasing attempt to integrate developmental perspective to performance on the WCST in children, research into improving interpretative accuracy on the base of normal children's performance remains rarely reported in Korea. Furthermore there has been no published data of the WCST performance on normal children in Korea, limiting its clinical use in children. The present study has two purposes. The first is to identify developmental trends in the WCST performance within the context of developmental expectation for brain maturation. The extent to which performance is confounded by gender and IQ level will also explored for accurate interpretation of test scores.

The second purpose is to identify the latent cognitive functions assessed by each scoring variable to yield clear interpretation about development of frontal lobe functions. Due to the lack of consensus of the frontal lobe functions assessed by each scoring variables, interpretation of the WCST results has been of limited use. Traditionally WCST scoring variables have been selectively used based on clinical evidence; "Categories Completed" hypothesized as a measure of conceptual formation and "Perseverative Errors" as a measure of difficulty to set-shift are the two variables that have been most frequently used. Furthermore previous studies differed in how WCST score were derived, making it difficult to compare results across studies. In the present study, 10 standard scoring variables(Heaton, 1981; Robinson, Heaton, Lehman, & Stilson, 1980) were investigated in order to enhance the availability of measures for frontal lobe functioning. In addition, identification of cognitive functions underlying each scoring variables is expected to lead to a clear interpretation of WCST findings.

Method

Participants

163 elementary school children from the 1st to 5th grade in a local elementary school in Seoul participated in the present study. One classroom from each grade in the school was randomly selected and the children from the selected classes with parental permission served as participants. Out of the 163 children, two children with FSIQ measured by KEDI-WISC below 80 and one 12-year-old boy were excluded from the study. The final sample of 75 girls and 85 boys was grouped into one of the 7, 8, 9,

Table 1. Means and Standard Deviations for Age and VIQ, PIQ, FSIQ scores.

Age Group	Age		VIQ		PIQ		FSIQ	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
7year old group								
Male(n=14)	7.31	.31	108.21	10.07	112.79	9.14	112.14	8.22
Female(n=16)	7.42	.30	103.00	12.94	104.50	14.25	104.25	13.07
Total(n=30)	7.37	.30	105.43	11.79	108.37	12.66	107.93	11.61
8year old group								
Male(n=18)	8.50	.32	113.56	13.57	115.33	11.20	116.00	11.23
Female(n=17)	8.63	.22	108.76	12.87	107.76	12.58	109.24	13.11
Total(n=35)	8.56	.28	111.23	13.26	111.66	12.32	112.71	11.61
9year old group								
Male(n=18)	9.46	.31	105.11	13.86	108.89	15.16	107.67	13.75
Female(n=13)	9.56	.27	109.31	11.83	114.23	11.56	112.85	12.48
Total(n=31)	9.51	.29	106.87	13.01	111.13	13.81	109.84	12.53
10year old group								
Male(n=17)	10.27	.28	115.00	9.11	117.35	11.61	117.88	9.39
Female(n=11)	10.25	.23	108.45	11.99	112.82	7.17	111.73	9.05
Total(n=28)	10.26	.26	112.43	10.63	115.57	10.19	115.46	9.59
11year old group								
Male(n=14)	11.37	.33	106.06	12.83	110.06	10.33	108.94	11.27
Female(n=16)	11.48	.34	104.89	10.24	113.67	12.71	110.11	10.72
Total(n=30)	11.42	.33	105.47	11.45	111.86	11.56	109.53	10.86
Total Group								
Male(n=85)	9.47	1.40	109.59	12.55	112.84	11.94	112.48	11.53
Female(n=75)	9.45	1.49	106.65	11.93	110.35	12.50	109.37	11.64
Total(n=160)	9.46	1.44	108.21	12.32	111.67	12.23	111.03	11.65

Note. VIQ = Verbal IQ; PIQ = Performance IQ; FSIQ = Full Scale IQ.

10, 11 year-old age groups. The means and standard deviations by age and sex for VIQ, PIQ, FSIQ are presented in Table 1. A multivariate ANOVA revealed that the children did not differ in their VIQ, PIQ, FSIQ by age, *Wilk's Lamda* = .893 $F(4, 155)$ = 1.426, *ns*, and *sex, Wilk's Lamda* = .980 $F(1, 155)$ = 1.028, *ns*. An interaction effect between sex and age was not found, either, *Wilk's Lamda* = .916 $F(4, 155)$ = 1.095, *ns*.

Measures

Korean Educational Developmental Institute-Wechsler Intelligence Scale for Children(KEDI-WISC): KEDI-WISC(1991) is a Korean version of WISC-R standardized and modified for Korean children aged 5 to 15 years. FSIQ, VIQ, PIQ were assessed for each child.

WCST Computer Version-2: WCST-CV2 (Heaton, 1991) is WCST administered using a computer according to standardized procedure instead of a examiner. The WCST consists of four stimulus cards and 128 response cards that depict figures of varying forms(crosses, circles, triangles, or stars), colors(red, blue, yellow, or green) and numbers of figures(one, two, three, or four). On the computer version, the four stimulus cards with following characteristics are presented on the top of the screen before the participants in left to right order: one triangle, two green stars, three yellow crosses, and four blue circles. The participant is then presented a deck of 64 response cards under the stimulus cards and instructed to match each consecutive card from the deck with one of the four stimulus cards, whichever one he or she think it maches. Feedback is given in the middle of the screen only whether each response is right or wrong and the participant is never told the correct sorting principle.

Once the participant has made a specified number of consecutive "correct" matched to the initial sorting principle(usually Color), the sorting principle is changed-to Form or Number-without warning, requiring the participant to use the computer's feedback to develop a new sorting strategy. The WCST proceeds in this manner through a number of shifts in a set among the three possible sorting categories(Color, Form, and Number).

The participant's responses were automatically scored by the software, yielding 16 Heaton et al.'s(1993) scoring variables: (1) Number of Trials Administered (2) Total Number of Correct Responses (3) Total Number of Errors (4) Percent of Errors (5) Trials to Complete First Category (6) Number of Categories Completed (7) Failure to Maintain set (8) Perseverative responses (9) Percent Perseverative Responses (10) Perseverative Errors (11) Percent Perseverative Errors (12) Nonperseverative Errors (13) Percent Nonperseverative Errors (14) Conceptual Level Responses (15) Percent Conceptual Level Responses (16) Learning to Learn. Among 16 variables, only 10 scoring variables except 5 redundant percent scores and Learning to learn[1] were included for the statistical analysis in the present study.

1) If the respondent fails to complete 2 or more categories, Learning to Learn cannot be calculated. To prevent listwise deletion of the data, it was excluded form the statistical analysis.

Procedure

All participants were individually administered the KEDI-WISC and the WCST as a part of a larger neuropsychological battery during 3 hour testing session. The children were seen at a classroom in their school during the three and half week period between from Feb. 4 to Feb. 27, 1999. Those tests were administered by one of the authors and three trained graduate students in clinical psychology.

WCST-CV2(Heaton, 1991) was administered using a pentium portable computer. The children's birth dates were confirmed using school records with permission from the parents and teachers.

Data Analysis

WCST raw scores were used to provide normative data. A multivariate ANOVA(PROC GLM[General Linear Models Procedure]) was used to examine main effects and interaction effects between age, sex, and IQ scores. The Pearson correlation between the 10 WCST scoring variables and FSIQ, VIQ and PIQ scores was assessed to examine the relationship between the IQ scores and the performance on the WCST. Further, the Pearson correlation between the three factor scores on the principal axis analysis and FSIQ, VIQ and PIQ scores were subject to the the Pearson correlation to identify the effect of IQ scores to the cognitive functions. The use of factor scores, in contrast to the original scoring variables, was to represent independent cognitive functions of WCST performance. Trend analyses for significant F values (α = .05) used orthogonal polynomial coefficients of General Linear Model-General Factorial Procedure to confirm long-term age effect. *Post-hoc* comparisons for significant F values (α = .05) were performed with Tukey HSD tests.

Bartlett's test of Sphericity and Kaiser-Meyer-Olkin Measure of Sampling Adequacy(MSA) was administered to assess the adequacy of the sample for the factor analysis. Acceptable level of MSA was .70 according to the guideline suggested by Kaiser(1974). Anti-image correlation matrix was also used to examine the data adequacy to conduct factor analysis. The factor analysis was performed using principal-axis factoring with oblique rotation since there exist significant correlations among scoring variables. The rotated factor patterns of the WCST scoring variables were examined for latent cognitive factors of the WCST. The number of meaningful factors to be retained for rotation was determined on the bases of two criteria: (a) eigenvalues of factors to be retained are greater than 1 (b) visual examination of the scree plot. SPSS Version 8.0 was used for all of the statistical analysis described above.

Results

The effect of age, sex, and IQ scores on the WCST performance

The main question of interest is whether the WCST performance is influenced by sex or/and IQ level. The multivariate analysis of variance(PROC GLM procedure) was use to examine main effects and interaction effects between age and sex. The means and standard deviations by age groups for 10 WCST scoring variables are presented in Table 2. The results

Table 2. Means and standard Deviations of the 10 WCST scoring variables by age groups

Scoring Variable	Age group									
	7		8		9		10		11	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
No. of Trials Administered	128.00	.00	126.88	3.46	120.94	14.34	118.00	16.21	120.22	13.31
Total Number of Corrects	56.86	21.15	69.22	17.62	69.74	17.21	74.10	18.74	76.94	14.23
Total Number of Errors	71.13	21.02	57.65	19.02	51.19	23.52	42.10	24.74	42.02	18.57
Perseverative Responses	24.80	.77	24.62	10.27	26.25	15.27	19.28	10.78	19.38	9.19
Perseverative Errors	22.43	7.03	22.76	8.18	21.84	10.68	21.00	11.94	20.17	8.17
Nonperseverative Errors	48.70	21.58	32.41	18.70	22.23	10.11	23.09	14.47	25.16	9.90
Conceptual Level Responses	36.23	25.48	56.08	23.74	65.84	17.90	59.54	24.38	64.88	14.32
No. of Categories Completed	1.70	1.51	3.29	1.96	2.83	1.94	4.23	2.07	4.11	2.24
Trials to Complete First Category	66.03	46.98	38.57	35.91	35.67	37.75	33.57	37.75	32.91	33.63
Failure to Maintain Set	1.33	1.24	1.54	1.19	1.80	1.72	1.71	1.69	2.00	1.65

Note. n = 160.

of multivariate analysis of variance(PROC GLM procedure) for the 10 WCST scoring variables by age sex are presented in Table 3. The WCST performance showed a significant difference among age groups, wilk's Lamda = .570, $F(4,155) = 1.028$, $p < .01$; but sex difference was not significant, *Wilk's Lamda* = .958, $F(1,155) = .935$, *ns*; the interaction effect between age groups and sex was not significant, either, *Wilk's Lamda* = .775, $F(4,155) = 1.095$, *ns*. As can be seen in Table 3, 8 of the 10 scoring variables showed significant age effects of the remaining two variables, one (Perseverative Responses) showed age effect approaching significance, $F(4,155) = 2.434$, $p = .05$. By contrast, Failure to Maintain Set was the only scoring variable that showed no significant age effect, $F(4,155) = .921$, *ns*.

As can be seen in Table 5, very modest correlation were found between VIQ scores and Nunber of Trials Administered, $r(160) = -.21$, $p < .01$, Total Number of Errors, $r(160) = -.17$, $p < .05$, and Number of Categories Completed, $r(160) = .24$, $p < .01$; between PIQ scores and Number of Trials Administered, $r(160) = -.20$, $p < .01$, Total Number of Corrects, $r(160) = .19$, $p < .01$, Total Number of Errors, $r(160) = -.25$, $p < .01$, and Nonperseverative Errors, $r(160) = -.25$, $p < .01$, Conceptual Level Responses, $r(160) = .22$, $p < .01$, Number of Categories Completed, $r(160) = .31$, $p < .01$; between FSIQ scores and Number of Trials Administered, $r(160) = -.24$, $p < .01$, Total Number of Corrects, $r(160) = .17$, $p < .05$, Total Number of Errors, $r(160) = -.24$, $p < .01$, Nonperseverative Errors, $r(160) = -.23$, $p < .01$, Conceptual Level Responses, $r(160) = .20$, $p < .05$, Number of Categories Completed, $r(160) = .31$, $p < .01$. When Compared with factor scores, IQ scores showed the very modest correlation with the Conceptual Formation factor as can be seen in Table 6: the factor score of Factor

Table 3. MANOVA on the 10 WCST scoring variables by age groups and sex

Independent Variables	Dependent Variables	Wilk's Lamda	Univariate *F*	df	Sig.	*post-hoc*[a]
Sex	No. of Trials Administered		.09	1	.77	
	Total Number of Corrects		1.27	1	.26	
	Total Number of Errors		.82	1	.37	
	Perseverative Responses		.59	1	.44	
	Perseverative Errors	.96	.49	1	.49	
	Nonperseverative Errors		1.37	1	.24	
	Conceptual Level Responses		.78	1	.38	
	No. of Categories Completed		.92	1	.34	
	Trials to Complete 1st Category		.74	1	.39	
	Failure to Maintain Set		.03	1	.86	
Age	No. of Trials Administered		4.49	4	.00	7>10,11; 8>10
Group	Total Number of Corrects		5.79	4	.00	7> 8, 9, 10, 11
	Total Number of Errors		10.17	4	.00	7>9,10,11; 8>10,11
	Perseverative Responses		2.43	4	.05	
	Perseverative Errors	.57**	2.76	4	.03	9>11
	Nonperseverative Errors		9.88	4	.00	7> 8, 9, 10, 11
	Conceptual Level Responses		8.03	4	.00	7> 8, 9, 10, 11
	No. of Categories Completed		8.54	4	.00	7> 8, 9, 10, 11
	Trials to Complete 1st Category		4.15	4	.00	7> 8, 9, 10, 11
	Failure to Maintain Set		.92	4	.45	
Age group	No. of Trials Administered		.40	4	.81	
×	Total Number of Corrects		.91	4	.46	
Sex	Total Number of Errors		1.10	4	.36	
	Perseverative Responses		1.39	4	.24	
	Perseverative Errors	.78	1.34	4	.26	
	Nonperseverative Errors		.58	4	.68	
	Conceptual Level Responses		1.08	4	.37	
	No. of Categories Completed		.79	4	.54	
	Trials to complete 1st category		.97	4	.43	
	Failure to Maintain Set		1.34	4	.26	

Note. a = Tukey HSD.
*$p < .05$. **$p < .01$.

Table 4. The Pearson correlation coefficient matrix between the 10 WCST scoring variables and VIQ, PIQ, and FSIQ scores.

Scoring Variable	IQ scores		
	VIQ	PIQ	FSIQ
No. of Trials Administered	-.21**	-.20**	-.24**
Total Number of Corrects	.11	.19**	.17*
Total Number of Errors	-.17*	-.25**	-.24**
Perseverative Responses	-.11	-.12	-.13
Perseverative Errors	-.10	-.12	-.12
Nonperseverative Errors	-.15	-.25**	-.23**
Conceptual Level Responses	.13	.22**	.20*
No. of Categories Completed	.24**	.31**	.31**
Trials to Complete First Category	-.13	-.13	-.15
Failure to Maintain Set	-.08	-.02	-.06

Note. n = 160.
*p<.05. **p<.01.

Table 5. The Pearson correlation coefficient matrix among the 10 WCST scoring variables

Scoring variables	1	2	3	4	5	6	7	8	9	10
1	1.00									
2	-.13	1.00								
3	.59**	-.84**	1.00							
4	.48**	-.37**	.55**	1.00						
5	.48**	-.38**	.56**	.99**	1.00					
6	.48**	-.84**	.91**	.19*	.20**	1.00				
7	-.28**	.95**	-91**	-.46**	-.47**	-.87**	1.00			
8	-.57**	.74**	-.88**	-.53**	-.54**	-.80**	.84**	1.00		
9	.30**	-.69**	.71**	.27**	.28**	.71**	-.74**	-.73**	1.00	
10	.26**	.61**	-.37**	-.13	-.13	-.38**	.56**	.11**	-.24**	1.00

Note. 1 = Number of Trials Administered; 2 = Total Number of Corrects; 3 = Total Number of Errors; 4 = Perseverative Responses; 5 = Perseverative Errors; 6 = Nonperseverative Errors; 7 = Conceptual Level Responses; 8 = Number of Categories Completed; 9 = Trials to Complete First Category; 10 = Failure to Maintain Set.
n = 160.
*p<.05. **p<.01.

I(Conceptual Formation. and VIQ, $r(160) = -.17$, $p < .01$, PIQ, $r(160) = -.26$, $p < .01$, and FSIQ scores, $r(160) = -.24$, $p < .01$.

Developmental Trends of the 10 WCST scoring variables

Trend analyses revealed that age had a significant linear effect($p < .05$) on 9 WCST scoring variables except Failure to Maintain Set($p > .05$). Nonperseverative Errors, Number of Categories Completed, Trials to Complete First Category also showed significant quadratic effect($p < .05$). Thus it can be concluded that WCST performance gradually improved with age through 7 to 11 years of age but specific pattern of developmental change appear to be different depending on the scoring variables.

Post-hoc analysis(Tukey HSD) was used to clarify the point of developmental spurts by comparing adjacent age groups for each of the 9 scoring variables. Despite the main age effect, none of the adjacent age group comparisons was significant for Number of Trials Administered, Total Number of Errors, Perseverative Responses, Perseverative Errors. There was a significant difference in between 7- to 8-year-olds in the following 5 scoring variables: Total Number of Correct Responses, Nonperseverative Errors, Conceptual Level Responses, Number of Categories Completed, Trials to Complete First Category.

The cognitive functions underlying the 10 WCST scoring variables

When data were first examined to determine the appropriateness for factor analysis, most variables showed correlations higher than .70 as can be seen in Table 5. The result of Bartlett's test of Sphericity, $\chi^2(45, n=160) = 2879.89$, $p < .01$ revealed that there exists common factors in the data. MSA(.78) was proved itself as acceptable level of appropriateness. Anti-image correlation matrix also showed that MSA's of 10 scoring variables are all sufficient enough to conduct factor analysis.

A principal axis factoring method was used to extract latent common factors for the WCST scoring variables. The rotated factor patterns along with their corresponding factor loadings are presented in Table 5. Three factors with eigenvalue greater than 1 accounted for 90.88 % of variance. The Factor Ⅰ accounted for approximately 60.24% of the common variance and included six variables. They had factor loading higher than .75 on Factor I: Nonperseverative Errors, Total Number of Errors, Conceptual Level Responses, Total Number of Corrects, Number of Categories Completed, Trials to Complete First Category. This factor was interpreted as "conceptual formation". The Factor Ⅱ, accounting for approximately 18.52% of the common variance, had two variables, Perseverative Responses and Perseverative Errors, with loading higher than .99. This factor was interpreted as "perseveration". The Factor Ⅲ accounted for approximately 12.12% of the common variance had high factor loadings on the Failure to Maintain Set and Number of Trials Administered, and thus interpreted as "ability to sustain attention".

Discussion

The present study addressed two issues that are

Table 6. The oblique Rotated Factor Pattern of the 10 WCST scoring variables.

Scoring Variables	Factor			communality (h^2)
	1	2	3	
Nonperseverative errors	.97	.23	-8.186E-02	.97
Total Number of Errors	.96	.58	-3.020E-02	.96
Conceptual level responses	-.95	-.49	.37	.99
Total Number of Corrects	-.89	-.39	.51	.98
Number of Categories Completed	-.89	-.55	-.14	.88
Trials to Complete First Category	.76	.30	-8.721E-02	.58
Perseverative Responses	.39	.99	9.666E-02	.99
Perseverative Errors	.40	.99	8.897E-02	.98
Failure to Maintain Set	-.38	-.14	.71	.60
Number of Trials Administered	.47	.48	.64	.75
eigenvalues	6.02	1.85	1.21	
Percent of variance	60.24	18.52	12.12	
cumulative percent of variance	60.24	78.76	90.88	

Note. 1 = Conceptual Formation; 2 = Perseveration; 3 = Ability to Sustain Attention.
n = 160.

essential to clinical utility of the WCST with children. The purpose of the present study was to use a large normative sample to identify and explain the developmental trends and a latent cognitive function for the 10 WCST scoring variables in school aged children. The findings of this study strongly support the presence of the developmental spurt consistent with what was reported by Chelune and Baer (1986) and Heaton et al. (1993). The present results confirmed the presence of the three cognitive functions (Conceptual Formation, Perseveration, Ability to Sustain Attention) which underlie the performance on the WCST. Moreover, these factors provide an economical guideline to differentiate and classify the developmental spurt presented by the 10 scoring variables.

The effect of sex and IQ scores on the WCST performance

The findings of no effect of gender on the WCST scores were also consistent with the previous research (Chelune and Baer, 1986; Heaton et al, 1993; Levin et al, 1991; Welsh et al, 1991), suggesting that boys and girls do not show any different pattern in developmental change.

The WCST performance in the present study was presented to covary with intellectual functions in children: very modest correlations were reported between FSIQ, VIQ, and PIQ scores and Conceptual Formation factor. There have been consistent data suggesting that Categories Completed which

Table 7. The oblique Rotated Factor Pattern of the 10 WCST scoring variables.

Scoring Variables	Factor			communality (h^2)
	1	2	3	
Nonperseverative errors	.97	.23	-8.186E-02	.97
Total Number of Errors	.96	.58	-3.020E-02	.96
Conceptual level responses	-.95	-.49	.37	.99
Total Number of Corrects	-.89	-.39	.51	.98
Number of Categories Completed	-.89	-.55	-.14	.88
Trials to Complete First Category	.76	.30	-8.721E-02	.58
Perseverative Responses	.39	.99	9.666E-02	.99
Perseverative Errors	.40	.99	8.897E-02	.98
Failure to Maintain Set	-.38	-.14	.71	.60
Number of Trials Administered	.47	.48	.64	.75
eigenvalues	6.02	1.85	1.21	
Percent of variance	60.24	18.52	12.12	
cumulative percent of variance	60.24	78.76	90.88	

Note. 1 = Conceptual Formation; 2 = Perseveration; 3 = Ability to Sustain Attention.
n = 160.

constituting Factor I(Conceptual Formation) in the present study correlated significantly with VIQ(Chelune and Baer, 1986, Heaton et al, 1993; Reader, Harris, Schuerholz, & Dencla, in press). Based on these results, it can be assumed that there is a overlap between VIQ and the conceptualization ability measured by the WCST. It can be argued that the VIQ by its verbal component is more closely affiliated with Conceptualization. In the present study, we didn't exercise analysis of covariance of IQ because if the covariate shares variance with both independent and dependent variables, controlling IQ may remove a portion of variance directly attributable to the cognitive function underlying the performance on the WCST. The question of whether the underlying cognitive factor(Conceptual Formation) is really a function of frontal lobe or if IQ needs further studies with appropriate research designs.

Developmental Trends of the 10 WCST scoring variables.

In the present study, children's WCST performance linearly improved with age in all WCST scoring variables except for one variable (Failure to Maintain Set). Failure to find linear trend in the variable might be explained by the inherent nature of the variable. That is, in contrast to the other WCST scoring variables, a high score on the Failure to Maintain Set might not necessarily reflect an inferior performance(Koren, Seidman, Harrison, Lyons, Kremen, Caplan, Goldstein, Faraone, & Tsuang, 1998) because

in order to "fail to maintain set", one has to acquire it first. Thus a low score on this variable might be reflective of either performance superb (i.e. perfect maintenance of set) or extremely poor performance (i. e. no set has ever been acquired).

Examination of the developmental spurt for the five scoring variables constituting Factor I(Conceptual Formation) suggested some correspondence with known stages of frontal growth spurt between 7 and 9 years of age reported in previous research such as the normative electroencephalographic work(Thatcher, 1991), stages of concrete operation period(7 to 11 years) and conceptual shift(by the age 8) in the study of conceptual acquisition (Gholson & Beilin, 1979; Stevenson, 1968). This study found that children's performance on Concept Formation Factor (Total Number of Corrects, Nonperseverative Errors, Conceptual level responses, Number of Categories Completed, Trials to complete first category) showed a developmental spurt between age 7 to 8 followed by no further change. Nonperseverative Errors, Number of Categories Completed, and Trials to Complete first Category also showed significant quadratic effects in trend analysis, further supporting the developmental shift consistent with cognitive developmental theories. In other words, these quadratic curves represent the performance profile which shows a substantially increasing proficiency in WCST performance of those scoring variables from age 7 to 8 and through 11 years olds. These findings are similar to those of other investigators who have studied samples of normative children(Chelune & bear, 1986; Chelune & Thompson, 1987; Welsh et al, 1991).

On the contrary, performance on Perseveration Responses and Perseveration Errors, constituting the Factor II(Perseveration) showed a different developmental trend from the Factor I. The developmental advance of 7 to 8 year olds in the Perseveration Responses observed by Welsh et al. (1991) and that of 6 to 7 year olds in Perseveration Errors reported by Chelune and Baer(1986) were not replicated in the present study. Trend analyses revealed a gradual linear improvement with age in both measures. Given that "perseveration" is a significant impairment factor in the WCST performance in clinical groups (Koren et al, 1998; Barkley, Grodzinsky, & Dupaul, 1992; Robinson, Heaton, Lehman, & Stilson, 1980), further investigation is needed to understand the developmental pattern of Perseveration Responses and Perseveration Errors with normal children and adolescents.

The Cognitive functions underlying the 10 WCST scoring variables

One of the goals of this study was to examine the factor structure of the WCST in normal children. To our knowledge, no such effort has been reported in the literature. In this study the 10 WCST scoring variables could be reduced to three factors which were interpreted as Conceptual Formation, Perseveration, and Ability to Sustain Attention. Interestingly, the three factor solution detected in this study closely corresponds to the one consistently identified by studies with adult schizophrenic patients(Koren et al, 1997; Sullivan et al, 1992), except that the proportions of variance accounted for by the factor were different. In other words, in the present study, Conceptual Formation was represented as a major factor which explained approximately 60% of the

common variance. Perseveration was a second factor which account for approximately 20% of the common variance. On the contrary, Perseveration was represented as a major factor which accounted for approximately 60% of the common variance in adult schizophrenics. Based on these results, therefore, it can be considered that the pattern of performance on the three cognitive functions might be used as the index to enhance diagnostic sensitivity. Moreover, the three cognitive factors underlying performance on the WCST bear close resemblance to the source of performance on the WCST mentioned by Heaton(1981): conceptualization, inhibition, ability to maintain set. These findings are important that identification of cognitive functions underlying each scoring variables is expected to lead to a clear interpretation of WCST findings.

Applicability of main findings

The multiple scoring variables of the WCST(Heaton, 1981) have never been submitted to factor analysis in children, which could reduce redundancies of the many scoring systems. In the present study, we used an expanded scoring system developed by Heaton(1981), to differentiate multiple cognitive processes that required to the performance on the WCST. This was the first study to use 10 WCST scoring variable in normal children, to our knowledge. The three factor solution detected in this study provides a more accurate and reliable guideline to interpret high level cognitive abilities measured by the WCST. This approach is important for two reasons. First, the extracted factor structure provides an empirical framework for future examination of the construct validity of the WCST and for studying the cognitive and neural mechanism which underlie performance. Second, a better understanding of the WCST will enhance its value with respect not only to assessment and diagnosis but also to treatment. The findings of the developmental spurt in the present study provide strong support for the notion that conceptualization is the source of performance on the WCST(Heaton, 1981). Although the present study does not directly address the sensitivity of the WCST to frontal lobe functioning in children, comparison of their performance with age norm could suggest some useful hypothesis for the development of conceptual formation ability mediated by frontal lobe.

Directions for future research

The fruitful direction for future research include a study to examine the construct validity, the tests previously demonstrated to be sensitive to frontal lobe function(i.e. test with demonstrated criterion validity), other that the WCST, to identify evidence supporting the convergent validity of the WCST factors as potentially valid measure of the frontal lobe functions. Future investigations of factorial structure against clinical group might lead to enhancing diagnostic specificity and sensitivity. Different clinical group such as ADHD or neurological patient group such as Seizure disorder may differ on the topography of the three factors according to their cognitive deficit. In subsequent studies, criterion validity of each of the factors should be evaluated by administrating neuropsychological tests that are known to specifically measure the factor. The stability of the factor structure should also be examined with a sample

including adolescents older than 11-years of age in future studies.

The limitations of the present study in terms of the generalization resulting from use of computer version of the WCST. As there was no examination about the performance difference induced by computer administration in normal children, it is not all clear whether computer administration itself fertilize or disturb the performance of children. The effect of the computer versus in-person administration is the significant issue requiring clarification.

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위스콘신 카드 분류검사의 발달추세연구 -7~11세 아동을 중심으로-

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본 연구는 학령기 정상 아동집단을 대상으로 위스콘신 카드분류검사(WCST)의 10개 채점지표에 나타나는 발달추세를 검증하고 이들 채점지표가 측정하는 인지요인을 파악하는 것을 목적으로 실시되었다. 컴퓨터 버전 WCST(Heaton, 1991)을 7세에서 11세 연령범위의 초등학생 160명에게 실시하였다. KEDI-WISC로 측정하였을 때 이들 아동의 전체지능은 80에서 138(M=112.02, SD=11.77)의 범위에 속하였으며 연령집단별 전체지능의 유의미한 차이는 나타나지 않았다. WCST의 10개 채점지표를 사용하여 주축요인화법(principal axis factoring)을 사교회전 방법(oblique rotation)을 사용하여 실시한 결과 아이겐값이 1이상인 3개의 요인이 추출되었으며 이들 요인은 '개념형성(요인 I: 설명변량 60.24%)', '보속성(요인 II: 설명변량 18.52%)', '주의유지능력(요인 III: 설명변량 12.12%)으로 해석되었다. 7~11세까지 5개의 연령집단의 수행을 분석하였을 때 10개의 채점지표중 '지속실패'를 제외한 9개의 채점지표에서 연령집단의 주효과가 유의미한 것으로 나타났다. 그러나 성별 및 성별과 연령의 상호작용 효과는 유의미하지 않았다. 요인 I에 가장 높은 요인 부하값을 나타낸 '전체시행수', '비보속오류수','개념수준반응수', '완성범주수'와 '첫범주완성시행수'의 5개 채점지표는 모두 7세에서 8세 사이에 유의미하게 수행이 향상되는 것으로 나타났다. 반면 요인 II에 높은 요인값을 나타낸 '보속오류수'는 9세에 비하여 11세에서 유의미하게 감소하는 것으로 나타났다. 이러한 결과는 WCST가 단일 인지기능을 측정하기보다는 서로 다른 발달 경로를 가진 중다인지기능을 측정하는 도구임을 지지하는 것이다.

주요어 : WCST, 발달추세, 정상아동, 인지요인