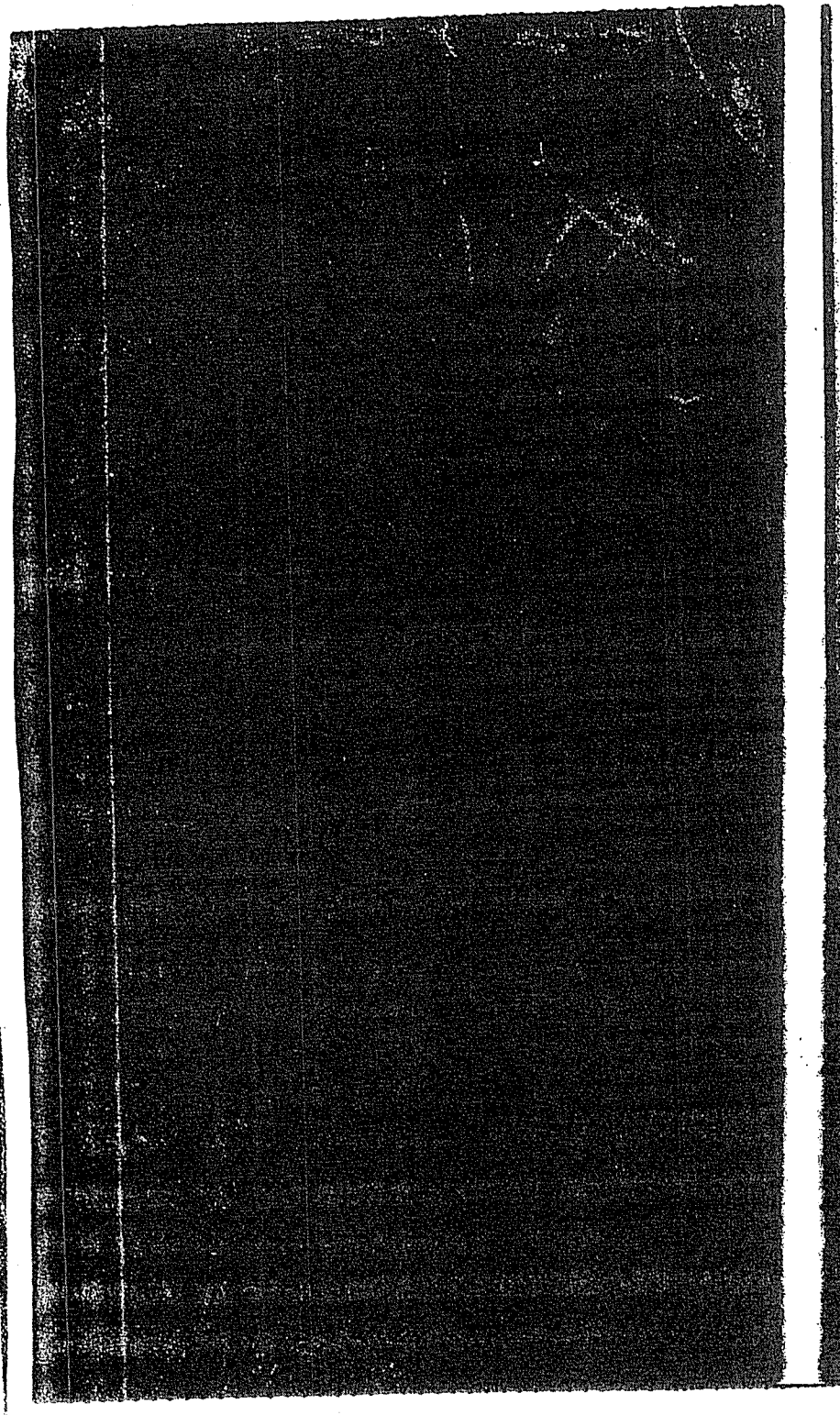

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Standardization of the Contingency Naming Test (CNT) for School-Aged Children: A Measure of Reactive Flexibility.

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Abstract

The Contingency Naming Test (CNT) was developed by H.G.Taylor (Taylor *et al.*, 1987) to assess reactive flexibility and speed of name retrieval in school-aged children, and involves two baseline naming tasks, a one-dimensional switching task, and a two-dimensional switching task. At present the applicability of the CNT is limited as it lacks normative data and its clinical validity is not yet well established. Two separate studies are reported to address these limitations. Study 1 generated developmental normative data for 381 children aged between 7 and 15 years. The results indicated that the CNT is suitable for children aged 7 to 15 years. Age-related differences were found on all trials, although the two-dimensional switching task was the most discriminating. Accuracy improved dramatically between 7 and 9 years of age and only slightly thereafter, whereas speed improved steadily across the age range, especially between the ages of 7 to 9 years, and 11 to 13 years. Accuracy on the CNT was similar for boys and girls, however girls were quicker on trials 1 to 3. Study 2 examined the clinical validity of the CNT by contrasting the performance of four groups of children aged 12 to 18 years: early-treated phenylketonuria (PKU), n=12; survivors of acute lymphoblastic leukemia (ALL), n=20; survivors of bacterial meningitis (BM), n=79; and healthy controls, n=79. All three clinical groups exhibited impairments on the CNT when compared to the control group. The PKU and ALL groups performed less efficiently and made more errors than the control group on all tasks, whereas the BM group made significantly more errors on the two-dimensional shifting task. In conclusion, the CNT is sensitive to cognitive development and to impairments associated with childhood neurological conditions, and is a useful clinical tool for the assessment of reactive flexibility in children aged 7 years and older.

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Introduction

Reactive flexibility is a term proposed by Grattan and Eslinger (1989) to describe the capacity to shift response patterns to satisfy changing demands. This capacity is associated with the ability to inhibit learnt behavior, shift attention, self-monitor and regulate performance, and is important for the acquisition of new information and skills, social interaction and educational achievement. Behavioral problems in these areas are often described in patients with prefrontal lesions, but more specifically when the lesions involve the dorsolateral region (Grattan & Eslinger, 1991). Individuals with lesions in this region are generally considered rigid, ritualistic and predictable. They become frustrated when rules are altered, activities abruptly changed, or their routine disturbed. These individuals exhibit inadequate behavior regulation, and are also likely to experience difficulty multi-tasking, preferring to work on one thing at a time.

A series of experiments in the 1980's involving rhesus monkeys indicated disinhibition and inflexibility following lesions to the prefrontal cortex (Diamond & Doar, 1989; Diamond & Goldman-Rakic, 1989; Diamond, Zola-Morgan, & Squire, 1987; Goldman-Rakic, 1987;). Many of these experiments involved the A-not-B task. In this task the subject observes an object being hidden in one of two wells and after a delay is allowed to reach for the object. The object is hidden in well (A) until the subject demonstrates learnt behavior, and then the placement of the object is reversed to well (B). An A-not-B error, or perseverative error, occurs when the subject continues to search at the original well (A) on the reversal task. Mastery on the reversal task requires the ability to recall the position of the object, as well as the capacity to inhibit habitual behavior and shift to a new response pattern. Non-lesioned adult rhesus monkeys mastered the A-not-B task relatively easily, however perseverative errors were common following dorsolateral lesions (Diamond & Goldman-Rakic, 1989). Interestingly, the performance of monkeys with significant memory deficits (ie, bilateral lesions of the hippocampus) was also impaired but they did not exhibit the perseverative errors of the dorsolateral lesioned monkeys (Diamond, Zola-Morgan, & Squire, 1987). More recently, Eslinger and Grattan (1993) examined the neural structures related to reactive flexibility by studying adult human patients with acquired focal lesions (frontal, basal ganglia, and posterior cortical). Their findings indicated that reactive flexibility is dependent on a frontal-striatal system, implicating both the prefrontal cortex and basal ganglia.

Infants as young as 12 months of age have shown the capacity to inhibit habitual behavior and shift to an alternative response pattern (Diamond, 1985; Diamond & Doar, 1989; Diamond & Goldman-Rakic, 1989;). In the attempt to map the development of these processes in children 3½ to 7 years of age, Gerstadt, Hong, and Diamond (1994) designed the "day-night" test. In this task subjects were instructed to say "day" when presented with a black card with a moon and stars, and "night" for a white card with a sun. Children under the age of 5 years struggled on this task, whereas children aged 6 to 7 years performed well. Espy (1997) suggests that this task may be too difficult for young children as it requires them to inhibit and switch simultaneously. To address this problem, Espy (1997) developed the Shape School test, which involves four conditions: control, inhibit, switch, and both (inhibit and switch). From her developmental data Espy (1997) concluded that inhibition efficiency improved significantly between 3 to 4 years of age, whereas switching skills showed development from

4 to 5 years of age. Also, children younger than 5 years struggled on the combined cond in which they had to both inhibit and switch.

In school-aged children simple conflict tasks have been used to investigate inhib control and the capacity to shift behavior. Like the "day-night" test, simple conflict involve the retention of two or more rules, the inhibition of a habitual response, and a sh a less natural or conflicting action. For example, subjects may be instructed to tap once v the experimenter taps twice and twice when the experimenter taps once (Becker, Isaa Hynd, 1987). Developmental studies indicate that by 6 years of age most children mastered simple conflict tasks (Becker, Isaac, & Hynd, 1987; Passler, Isaac, & Hynd, 1985 simple conflict tasks are hampered by low "ceiling effects", more demanding tasks are req to investigate the further development of reactive flexibility in school-aged children. Tests as the Wisconsin Card Sorting Test (WCST; Berg, 1948), Stroop Test (Stroop, 1935). Trails B (Army Individual Test Battery, 1944) are more complex and have documented val with school-aged children. Perseverative errors on the WCST reflect difficulty inhibiti previous response pattern and shifting to an alternative response set. Three separate stu have shown that the number of perseverative errors on the WCST declines dramati between 7 and 13 years of age (Chelune & Baer, 1986; Kelly, 2000; Levin *et al.*, 19 indicating significant gains in inhibitory control and shifting behavior during mi childhood. Performance improvements on Trails B and Stroop Test have also been reporte children aged 7 to 13 years (Kelly, 2000).

The Contingency Naming Test (first cited in Taylor, Albo, Phebus, Sachs, & Bierl, 1 was developed by H.G.Taylor as an alternative measure of reactive flexibility and enables assessment of both simple and multi-dimensional shifting behavior. The test begins with naming tasks (trials 1 & 2), followed by a one-dimensional switching task (trial 3), and a t dimensional switching task (trial 4). The stimulus card for the CNT consists of an arra colored external shapes, each of which contains a smaller internal design. On each of the t the child is instructed to name either the color or external shape of each design accordin set rules. In trial 1 the subject names the color of the designs and in trial 2 the subject r name the external shape. Trial 3 is significantly more difficult and involves an "if then else one-dimensional switching rule. The rule is to name the color of the design if the internal external shapes match, and to name the external shape if they do not match. To follow this r the subject must switch rapidly between two response sets. Finally, trial 4 utilizes a t condition rule, whereby the subject maintains the response pattern from trial 3 but in spe circumstances the response sets are reversed. Specifically, the subject is required to reverse previous contingency if a backward arrow appears above the design. Thus, instead of nam color when the internal and external shapes match and the external shape when they do match, the subject must say the external shape when the internal and external shapes m and the color when they do not match.

Given that the CNT incorporates a complex two-dimensional switching task, it may more sensitive to reactive inflexibility than traditional tests such as the WCST, Trails B Stroop Test. Recent outcome studies suggest that the CNT is sensitive to cognitive impairm in children with histories of bacterial meningitis (Grimwood *et al.*, 2000), low birth weig

(Taylor *et al.*, 1998) and early onset insulin dependent diabetes (Northam *et al.*, in submission), and in women with Fragile X (Mazzocco *et al.*, 1992). However unlike traditional measures, the CNT lacks standardized scoring procedures and a normative database. The purpose of this paper was to address these limitations by presenting results from two studies that examined the psychometric characteristics of the CNT. The first study collated normative data for children aged between 7 and 15 years and investigated the developmental transitions in inhibitory control and reactive flexibility. The second study investigated the test's clinical validity by comparing three clinical samples with a control group.

STUDY 1

The three main objectives of this study were : 1) to describe CNT administration procedures, 2) to collate normative data for children aged between 7 and 15 years, and 3) to examine age and gender differences.

Method

Subjects

The normative sample consisted of 381 children aged between 7.0 years to 15.11 years with approximately equal numbers of males (n=189) and females (n=192). The sample was divided into nine age groups. Demographic characteristics are listed in Table 1. The average estimated IQ of the total sample was 106.3, and all age groups had a mean estimated IQ above 100. Socio-economic status (SES) was estimated using the Daniel's Scale of Occupational Prestige (Daniel, 1983), the Hollingshead Two Factor Index of Social Position (1957), or the Hollingshead Four Factor Index of Social Status (1975) and categorized into three groups (low, middle and upper). The cut-off points for the groups were the lower and upper ternary for each SES measure. The normative sample could be classified as predominantly middle to low SES with approximately half of the families judged as middle class and one-third as working class. Age group differences on SES did not reach significance. The sample was collated from three centers: the Royal Children's Hospital, Melbourne, Australia (n=250); the Rainbow Babies and Children's Hospital, Cleveland, US (n=42); and McGill University, Montreal, Canada (n=89). All children had participated in research projects as healthy controls. Children with an estimated IQ below 80 were excluded.

Table 1. Characteristics of Normative Sample.

Age (years)	7	8	9	10	11	12	13	14	15
N	22	34	26	49	59	60	50	37	44
Male /Female (n)	7/15	18/16	15/11	21/28	29/30	30/30	28/22	21/16	20/24
IQ Mean	101.7	106.0	110.3	109.5	108.5	105.9	104.6	103.5	104.6
SES low /mid /upper (%)	55/40/5	26/55/19	27/42/31	43/35/22	45/43/12	30/58/12	32/48/20	19/67/14	28/51/.

Procedure

Children were administered the CNT by qualified psychologists according to the standar administration procedures described below. The assessment also included neuropsychological measures, however these were not standard across all subjects and wil be reported. IQ was estimated using one of three measurements: full version of the WISC (Wechsler, 1991); a four subtest shortform of the WISC-R (Wechsler, 1974); or a four-su version of the K-ABC (Kaufman & Kaufman, 1983).

CNT Stimulus Card

The stimulus card for the four experimental trials is a single laminated sheet of white paper three rows of nine designs colored blue, green or pink. Each design has a larger externa smaller internal shape (circle, square, triangle). Three designs on each row have an arrow them that point right to left. The sequence of shapes and colors is fixed across administr (see Appendix 1). A single row of seven designs, used for practice trials, appears on the r side of the stimulus card (see Appendix 2).

Administration

Trial 1

Practice task. Place the practice stimulus card in front of the child. The tester says, "Th naming test. In this test I'm going to ask you to name some colors and shapes. The first want you to learn is to name the colors. Let's try some." Point to appropriate designs an "We'll call this color green, this color pink and this color blue." Then ask the child to nam colors. "For practise, name the things in this row using the rule you just learned. Point with finger to keep your place. Start from this side and move across this way, from left to right." the child names all of the practice designs, point to the designs for which uncorrected

were made, and ask the child to name them. If the child does not spontaneously correct an error, provide the correct response. Record errors or self-corrections (corrected errors). The experimental task is administered when the child completes the row of practice designs successfully (ie. no uncorrected errors), or alternatively, when five practice trials have been administered.

Experimental task. Place the experimental stimulus card in front of the child. The tester says, "Now using the rule you just learned, I want you to name the things on this card. Start with the top row, then the middle, and then the bottom moving across this way, from left to right as you go. Go as quickly as you can without making mistakes. Point to each one as you name it. Ready, go." Record the time taken, errors and self-corrections.

Trial 2

Practice task. Return the practice stimulus card and say, "The next rule for you to learn is to name the shapes, the heavy outside ones." Point to the appropriate designs and say, "We will call this one a circle, this one a triangle, and this one a square." Then ask the child to name the three shapes. For practise, name the things in this row using the rule you just learned. Point with your finger to keep your place. Start from this side and move across this way" (from left to right). If the child made any uncorrected errors follow the procedure outlined in trial 1.

Experimental task. Place the experimental stimulus card in front of the child and say, "Now using the rule you just learned, I want you to name the things on this card. Start with the top row, then the middle, and then the bottom moving across this way, from left to right. Go as quickly as you can without making mistakes. Ready, go." The instruction to point with the finger, and to go from left to right across the top, middle, and bottom rows, can be continued on this and subsequent trials, or phased out if reminding is not necessary. Record the time taken, errors and self-corrections.

Trial 3

Practice task. Return the practice stimulus card and say, "Now I'd like to teach you a trickier rule. To learn this rule you'll have to pay attention to the little shapes inside the bigger ones." Point to some of the internal shapes. "The rule goes like this, when the inside shape matches the outside shape, you say the color." Point to the first design and say, "These two shapes match so you'd call this green. When the inside shape doesn't match the outside shape, you'd say the shape, the heavy, outside one." Point to the second design and say, "These two shapes don't match so you'd call this a triangle." Point to the first and second designs and ask the child to apply the new rule. Repeat the rule if the child gives incorrect responses and then go through the row of practice designs, following the same procedure used in the earlier trials. Any subsequent errors should be corrected as outlined in trial 1, but in addition, the rule should be repeated.

Experimental task. Place the experimental stimulus card in front of the child and say,

"Now using the rule you just learned, name the things on this card. Try to go quickly wi making mistakes, but if you have to slow down so as to not make mistakes, it's better to that way". Record the time taken, errors and self-corrections.

Trial 4

Practice task. Return to the practice stimulus card and say, "The rules get more difficult a go along but that makes the test more interesting. This time you'll use the same rule yo learned to name everything except for the ones with backwards arrows over them. Whe see a backwards arrow, that means to do it the backwards way. To do it the backwards wa name the color instead of the shape or the shape instead of the color. That's really tricky me show you what I mean". Demonstrate the rule for three designs with arrows over t First, point to the design covering the arrow with a finger and say, "If the backwards a wasn't here you would call this a triangle, because the shapes don't match." Remove the f and show the arrow. "But the backwards arrow is here, and to do it the backwards way yo the color pink instead". Repeat for the other two designs with arrows, and then ask the to name these three designs. Correct and re-explain rule if the child makes an error. Th through the practice row of designs, using the same procedures as outlined in trial 1. R the rule as part of the procedure for correcting errors made by the child in practice.

Experimental task. Place the experimental stimulus card in front of the child an "Again using the rule you just learned, name the things on this card. Try to go quickly wi making mistakes, but if you have to slow down so as to not make mistakes, it's better to that way". Try to administer the trial even if the child is having difficulty, but discontinue child becomes upset, or does not seem to know how to continue. Record the time taken, and self-corrections.

Scoring

Performance on the CNT is judged according to speed and accuracy.

1. ***Failed to complete*** refers to administrations in which children are unable to begin or fin trial. For example, a trial may be abandoned when the child is unable to understan instructions, or when the child becomes upset, or does not seem to know how to cont
2. ***Errors*** occur when a wrong response is provided and left uncorrected. The total numb errors is recorded for each trial and summed across trials (total errors).
3. ***Self-corrections*** refer to responses that are initially incorrect but then corrected by the The total number of self-corrections is recorded for each trial and summed across (total self-corrections).
4. ***Self-regulation*** is a summary score that takes into account both errors and self-correct "Errors" is multiplied by two in order to weight uncorrected errors more heavily than corrections. Self-regulation is calculated for each trial and a total self-regulation sc calculated using the total number of errors and self-corrections recorded across trials. values represent poor self-regulation. The formula for this variable is as foll self-regulation = (2 x errors) + self-corrections.

5. *Time* refers to the time taken (recorded in seconds) to complete each trial, and summed across trials (total time).
6. *Efficiency* rewards speed and accuracy, taking into account both time and error parameters. Efficiency is calculated for each trial, and a total efficiency score is also calculated using total time and total errors. In order to normalize the distribution and provide greater balance between errors and time, a square root transformation of errors is performed. High values represent efficient performance and the formula for this parameter is as follows: efficiency = [(1/time) / SQRT(errors+1)] x 100.

Statistical Analysis

The distributions of errors, self-corrections, and self-regulation were all positively skewed; accordingly, these variables were analysed with non-parametric tests. Changes across trials on these parameters were analysed using the Wilcoxon Signed Ranks test, age group differences were analysed using the Kruskal-Wallis test, and gender differences were analysed using the Mann-Whitney test.

Time and efficiency variables were normally distributed. Multi-factorial (age, gender, trial) repeated measures analyses of variance (ANOVAs) were conducted to assess change across trials for time and efficiency parameters. Group differences at each trial were analysed using 2 factor (age, gender) ANOVAs. Post-hoc tests were conducted using the Games-Howell test.

Results

The CNT normative data for children aged 7 to 15 years are listed in Tables 2 to 5.

Failed to Complete

No child failed to complete trial 1 or trial 2. Two children (0.5%) failed to complete trial 3 (aged 8 and 15), and six children (1.6%) failed to complete trial 4 (two aged 7, two aged 8, one each aged 11 and 15).

Errors

Trial and gender differences. The same proportion of children made errors on trial 1 and trial 2 (9%), however this increased to 37% on trial 3 and 72% on trial 4. Errors increased significantly between trials 2 and 3 (Z = -8.785, p < .001), and again between trials 3 and 4 (Z = -11.833, p < .001). There were no gender differences on total errors, or on the number of errors made during individual trials. Gender differences within each age group were also not significant.

Age differences. Significant age group differences were found on total errors (χ^2_8 = 41.533, p < .001). The 7-year-old age group made significantly more errors than the 8-year-old age group, and both these groups made significantly more errors than the older age groups. Age group differences were also identified within individual trials. On trial 1 (χ^2_8 = 18.058, p < .05), the 7-year-old age group made more errors than the other age groups with the

exception of the 8-year-old and 11-year-old age groups. On trial 2 the younger group 9-year-olds) tended to make more errors than the older groups, and the 7-year-olds m most errors on trial 3. On trial 4 (χ^2_8 = 40.861, p < .001) the 7-year-old age grou significantly more errors than the 8-year-old age group, and both groups made signi more errors in comparison to the older age groups. The majority (75%) of 7-year-olds a of the 8-year-olds made 3 or more errors on trial 4, reflecting the difficulty experience younger age groups on this trial. The 14-year-old and 15-year-old age groups tended t fewer errors on trial 4.

Table 2. Normative data for errors on the CNT.

Age (years)	7	8	9	10	11	12	13	1
Trial 1								
1 or more errors (%)	27	15	4	2	14	7	8	5
3 or more errors (%)	14	0	0	0	0	0	0	(
No. of errors (90th percentile)	2.9	1.0	0	0	1.0	0	0	(
Trial 2								
1 or more errors (%)	14	17	12	8	9	12	4	3
3 or more errors (%)	5	6	0	0	0	0	0	(
No. of errors (90th percentile)	1.0	1.0	1.0	0	0	1.0	0	(
Trial 3								
1 or more errors (%)	64	44	35	33	39	38	36	3
3 or more errors (%)	27	9	4	8	10	7	6	3
No. of errors (90th percentile)	8.8	2.0	1.0	2.0	2.1	2.0	2.0	1
Trial 4								
1 or more errors (%)	90	85	69	76	69	73	74	5
3 or more errors (%)	75	52	27	41	33	37	26	1
No. of errors (90th percentile)	17.6	9.6	5.9	6.0	5.1	6.0	4.9	3
Total								
1 or more errors (%)	95	91	77	84	81	83	80	7
3 or more errors (%)	73	62	42	47	42	45	42	1
No. of errors (90th percentile)	26.1	12.0	6.6	8.0	7.1	7.9	6.9	4

Self-corrections

Trial and gender differences. Similar proportions of children made self-corrections on trial 1 (35%) and trial 2 (38%), but these proportions increased to 68% on trial 3 and 73% on trial 4. Self-corrections increased significantly between trials 2 and 3 ($Z = -10.659, p < .001$), and again between trials 3 and 4 ($Z = -2.301, p < .05$). There were no gender differences on total self-corrections, or on the number of self-corrections made during individual trials. The only significant gender by age group interaction was found in the 10-year-old age group ($Z = -2.928, p < .01$), at which age boys made more self-corrections than girls.

Age differences. A significant age group main effect was found on total self-corrections ($x^2_8 = 16.590, p < .05$), with the 9-year-old age group making significantly more self-corrections than the 12-year-old, 14-year-old and 15-year-old age groups. No significant age group differences were identified on trials 1, 3 and 4, but on trial 2 ($x^2_8 = 40.861, p < .001$) the 7-year-old and 8-year-old age groups made significantly more self-corrections than the 12- to 15-year-old groups.

Table 3. Normative data for self-corrections on the CNT.

Age (years)	7	8	9	10	11	12	13	14	15
Trial 1									
1 or more self-corrections (%)	14	0	0	0	0	0	0	0	0
No. of self-corrections (90th percentile)	1.9	2.0	2.0	2.0	2.0	1.9	1.9	1.0	1.0
Trial 2									
1 or more self-corrections (%)	5	6	0	0	0	0	0	0	0
No. of self-corrections (90th percentile)	2.9	2.0	2.3	2.0	2.0	1.0	1.9	1.0	1.6
Trial 3									
1 or more self-corrections (%)	27	9	4	8	10	7	6	3	9
No. of self-corrections (90th percentile)	5.7	4.0	4.6	4.0	4.1	2.9	3.0	2.2	3.0
Trial 4									
1 or more self-corrections (%)	75	52	27	41	33	37	26	14	19
No. of self-corrections (90th percentile)	4.9	4.0	4.3	4.0	5.0	3.0	3.0	3.2	3.0
Total									
1 or more self-corrections (%)	73	62	42	47	42	45	42	19	36
No. of self-corrections (90th percentile)	13.5	10.2	10.5	11.0	10.0	6.9	7.0	6.2	7.0

Self-Regulation

Trial and gender differences. Self-regulation scores were similar on trials 1 and 2, however scores increased significantly from trials 2 to 3 ($Z = -12.301, p < .001$), and again from trial 4 ($Z = -12.164, p < .001$). High scores reflect poor self-regulation, and as expected, perfor deteriorated during the switching tasks. No significant gender differences were found.

Age differences. Total self-regulation decreased linearly with age ($x^2_8 = 40.861, p < .001$ 7-year-olds exhibited poorer self-regulation than the 8-year-olds, and both these age g displayed less self-regulation than children aged 9 to 15 years. Significant age group diffe on self-regulation were also found on individual trials. The 7-year-old and 11-year-o groups exhibited poorer self-regulation on trial 1 ($x^2_8 = 18.461, p < .05$), while on trial = 20.881, $p < .01$) the 7-year-old and 8-year-old age groups displayed poorer self-regu than the 12- to 15-year-old age groups. On trial 4 ($x^2_8 = 48.601, p < .001$) the 7-year-o group displayed poorer self-regulation than the 8-year-old age group, and both these g exhibited less self-regulation than the older children.

Table 4. Normative data for self-regulation on the CNT.

Age (years)	7	8	9	10	11	12	13	14	15
Trial 1									
Self-regulation score (median)	1	0	0	0	1	0	0	0	0
Self-regulation (90th percentile)	6.8	3.0	2.0	2.0	3.0	2.0	2.0	2.0	2.
Trial 2									
Self-regulation score (median)	1	1	1	0	0	0	0	0	0
Self-regulation (90th percentile)	4.8	3.6	3.3	2.0	2.0	2.0	2.0	1.0	2.
Trial 3									
Self-regulation score (median)	3	3	3	2	2	2	2	2	2
Self-regulation (90th percentile)	18.9	8.0	6.3	7.0	7.0	5.0	6.0	6.0	6.
Trial 4									
Self-regulation score (median)	15.5	8	5	5	5	5	4.5	3	4
Self-regulation (90th percentile)	36.2	20.6	13.2	13.0	13.1	13.9	10.8	8.4	1
Total									
Self-regulation score (median)	28.5	15	9.5	8	9.5	9	8	5	7
Self-regulation (90th percentile)	55.9	32.2	17.3	21.0	23.1	20.9	17.0	11.2	1

Age	Trial 1		Trial 2		Trial 3		Trial 4		Total	
	Time M(SD)	Efficiency M(SD)	Time M(SD)	Efficiency M(SD)	Time M(SD)	Efficiency M(SD)	Time M(SD)	Efficiency M(SD)	Time M(SD)	Efficiency M(SD)
7yr (n=22)	28.9(6.3)	3.2(1.1)	44.2(14.2)	2.4(0.8)	77.8(16.8)	0.9(0.4)	91.3(19.3)	0.5(0.3)	241.8(28.5)	0.2(0.1)
Male (n=7)	29.1(6.0)	3.0(1.0)	48.7(19.4)	2.2(1.1)	85.0(24.2)	0.7(0.3)	88.2(15.1)	0.4(0.1)	254.2(27.9)	0.1(0.1)
Female (n=15)	28.8(6.7)	3.4(1.2)	42.1(11.2)	2.5(0.7)	74.4(11.7)	1.1(0.4)	92.3(20.9)	0.5(0.3)	237.6(28.4)	0.2(0.1)
8yr (n=34)	24.8(5.2)	4.0(1.0)	37.8(13.3)	2.7(1.0)	65.1(13.0)	1.3(0.4)	80.2(19.7)	0.7(0.3)	205.0(31.4)	0.2(0.1)
Male (n=18)	25.6(5.8)	3.8(1.0)	40.9(15.4)	2.5(1.0)	65.9(12.6)	1.4(0.4)	80.8(19.5)	0.8(0.3)	208.2(28.4)	0.2(0.1)
Female (n=16)	23.9(4.6)	4.2(0.9)	34.3(9.9)	3.0(1.0)	64.3(13.7)	1.3(0.4)	79.6(20.6)	0.7(0.3)	202.1(34.7)	0.2(0.1)
9yr (n=26)	21.7(4.2)	4.7(1.0)	28.3(8.0)	3.7(1.0)	57.3(11.2)	1.6(0.5)	75.2(13.8)	1.0(0.4)	182.6(28.2)	0.4(0.2)
Male (n=15)	22.9(4.2)	4.5(0.8)	30.7(8.6)	3.3(0.8)	58.3(11.2)	1.5(0.4)	74.7(15.0)	1.0(0.4)	186.5(29.4)	0.3(0.1)
Female (n=11)	20.2(4.0)	5.0(1.1)	25.0(5.8)	4.1(1.1)	56.0(11.6)	1.7(0.6)	76.0(12.6)	0.9(0.5)	177.2(26.9)	0.4(0.2)
10yr (n=49)	20.7(3.9)	5.0(1.0)	27.1(6.8)	3.8(1.0)	52.9(11.2)	1.7(0.5)	74.8(18.6)	0.9(0.5)	175.5(31.4)	0.4(0.2)
Male (n=21)	21.4(3.4)	4.8(0.8)	29.6(7.9)	3.5(1.0)	53.3(11.4)	1.7(0.5)	75.9(18.4)	0.9(0.5)	180.1(29.8)	0.3(0.2)
Female (n=28)	20.1(4.2)	5.1(1.1)	25.2(5.2)	4.1(0.9)	52.7(11.3)	1.8(0.6)	74.0(19.0)	1.0(0.4)	172.0(32.6)	0.4(0.2)
11yr (n=59)	19.5(4.0)	5.1(1.1)	24.0(5.2)	4.2(1.0)	50.7(11.9)	1.8(0.6)	72.7(20.8)	1.0(0.5)	166.8(36.4)	0.4(0.2)
Male (n=29)	20.4(4.3)	4.8(1.1)	24.0(6.0)	4.3(1.1)	51.1(12.2)	1.8(0.6)	72.6(23.0)	1.1(0.5)	168.2(39.6)	0.4(0.2)
Female (n=30)	18.5(3.5)	5.4(1.0)	24.0(4.5)	4.2(0.9)	50.4(11.9)	1.7(0.6)	72.7(18.7)	1.0(0.5)	165.3(33.4)	0.4(0.2)
12yr (n=60)	18.4(3.3)	5.5(1.1)	22.6(6.4)	4.5(1.1)	47.3(10.5)	1.9(0.6)	65.6(15.3)	1.1(0.5)	153.8(29.0)	0.4(0.2)
Male (n=30)	18.9(3.6)	5.5(0.9)	24.8(8.0)	4.1(1.1)	48.2(12.3)	2.0(0.6)	63.6(14.7)	1.1(0.5)	155.5(32.9)	0.4(0.2)
Female (n=30)	17.9(2.9)	5.5(1.2)	20.4(3.0)	4.9(0.9)	46.3(8.5)	1.9(0.7)	67.5(15.8)	1.0(0.5)	152.1(24.9)	0.4(0.2)
13yr (n=50)	16.5(4.6)	6.2(1.4)	20.9(5.4)	5.0(1.2)	44.6(11.0)	2.1(0.7)	61.3(16.2)	1.2(0.6)	143.3(32.9)	0.5(0.2)
Male (n=28)	17.8(5.6)	5.8(1.5)	21.9(5.8)	4.8(1.1)	46.2(10.8)	2.0(0.6)	63.2(16.4)	1.2(0.6)	149.0(34.4)	0.5(0.2)
Female (n=22)	15.0(2.2)	6.7(1.1)	19.8(4.7)	5.1(1.3)	42.6(11.2)	2.2(0.8)	58.8(16.0)	1.3(0.6)	136.1(30.0)	0.5(0.2)
14yr (n=37)	16.8(3.2)	6.0(1.1)	21.4(6.0)	4.9(1.0)	41.9(7.4)	2.2(0.5)	58.9(12.2)	1.4(0.5)	139.1(22.0)	0.5(0.2)
Male (n=21)	17.8(3.4)	5.6(1.1)	22.0(3.9)	4.7(0.8)	44.1(7.4)	2.1(0.5)	60.9(12.9)	1.3(0.4)	144.8(19.9)	0.5(0.2)
Female (n=16)	15.6(2.6)	6.6(1.0)	20.7(8.0)	5.1(1.2)	39.0(6.4)	2.4(0.5)	56.4(11.2)	1.4(0.5)	131.6(22.9)	0.5(0.2)
15yr (n=44)	15.9(2.8)	6.3(1.1)	18.6(3.9)	5.4(1.0)	41.3(12.3)	2.3(0.7)	57.2(20.1)	1.4(0.6)	133.4(34.3)	0.5(0.2)
Male (n=20)	16.8(3.0)	5.8(1.1)	19.6(3.9)	5.2(0.9)	45.6(15.7)	2.1(0.8)	59.9(26.6)	1.3(0.6)	143.2(45.2)	0.4(0.2)
Female (n=24)	15.2(2.4)	6.7(1.0)	17.8(3.8)	5.6(0.9)	38.1(7.9)	2.4(0.7)	55.1(13.1)	1.4(0.6)	126.1(21.5)	0.6(0.2)
Total (n=381)	19.6(5.3)	5.3(1.4)	25.6(10.1)	4.2(1.3)	51.0(14.8)	1.8(0.7)	69.0(19.7)	1.1(0.5)	164.5(41.3)	0.4(0.2)
Male (n=189)	20.2(5.2)	5.1(1.3)	26.8(11.0)	4.1(1.3)	52.0(15.1)	1.8(0.6)	68.7(19.8)	1.1(0.5)	166.5(40.8)	0.4(0.2)
Female (n=192)	18.9(5.3)	5.5(1.5)	24.4(9.0)	4.4(1.3)	50.1(14.5)	1.9(0.7)	69.2(19.6)	1.1(0.5)	162.5(41.8)	0.4(0.2)

Time

Trial and gender differences. Time differed significantly across the trials ($F(3,1065)$ = 1922.297, $p < .001$). According to simple effects tests, time increased significantly between trials 1 and 2 ($F(1,355)$ = 353.255, $p < .001$), between trials 2 and 3 ($F(1,355)$ = 1892.413, $p < .001$), and between trials 3 and 4 ($F(1,355)$ = 477.144, $p < .001$). The mean total time for boys was significantly slower than for girls ($F(1,355)$ = 7.770, $p < .01$), and on average girls completed trial 1 ($F(1,362)$ = 14.952, $p < .001$), trial 2 ($F(1,363)$ = 20.222, $p < .001$) and trial 3 ($F(1,360)$ = 8.735, $p < .01$) more rapidly than boys. Gender differences on trial 4 and the gender by age group interactions were not significant.

Age differences. Total time declined significantly as age increased ($F(8,355)$ = 32.942, $p < .001$), with significant age group differences on trial 1 ($F(8,362)$ = 32.005, $p < .001$), trial 2 ($F(8,363)$ = 39.307, $p < .001$), trial 3 ($F(8,360)$ = 31.198, $p < .001$) and trial 4 ($F(8,357)$ = 10.893, $p < .001$). For all four trials, the 7-year-old and 8-year-old age groups were significantly slower than the older groups. The mean times for the 9- to 11-year-old age groups were similar, as were the mean times for the 13- to 15-year-old age groups.

Efficiency

Trial and gender differences. Simple effects tests revealed that efficiency declined between trials 1 and 2 ($F(1,355)$ = 189.618, $p < .001$), between trials 2 and 3 ($F(1,355)$ = 1330.583, $p < .001$), and between trials 3 and 4 ($F(1,355)$ = 323.540, $p < .001$). There was a trend for girls to achieve higher total efficiency scores, although this did not reach significance ($F(1,355)$ = 3.630, $p > .05$). On average, girls completed trial 1 ($F(1,362)$ = 20.272, $p < .001$), trial 2 ($F(1,363)$ = 11.743, $p < .01$) and trial 3 ($F(1,360)$ = 4.003, $p < .05$) more efficiently than boys, but the gender difference was not significant on trial 4 ($F(1,357)$ = 0.592, $p > .05$), nor were any of the gender by age group interactions.

Age differences. Total efficiency increased steadily with age ($F(8,355)$ = 5.134, $p < .001$), and significant age group effects were found on trial 1 ($F(8,362)$ = 22.726, $p < .001$), trial 2 ($F(8,363)$ = 26.735, $p < .001$), trial 3 ($F(8,360)$ = 9.187, $p < .001$) and trial 4 ($F(8,357)$ = 6.232, $p < .001$). On all four trials, the efficiency score increased significantly between ages 7 and 9 years and again between ages 11 and 13 years. Relatively little separated the 9- to 11-year-old age groups and the 13- to 15-year-old age groups.

Discussion

Performance on the CNT is summarized by several parameters. Time is an indication of speed of name retrieval, while self-regulation can be utilized as a measure of accuracy as it takes into account both errors and self-corrections. The efficiency variable, which penalizes errors and slow performance, was derived to enable concurrent assessment of speed and accuracy.

Relative to the naming tasks (trials 1 & 2), accuracy deteriorated on the one-dimensional switching task (trial 3) as shown by increases in the number of errors and self-corrections across those trials. Children were also significantly slower on the first switching task, usually requiring double the amount of time recorded on the naming tasks. Accuracy deteriorated even further on the two-dimensional switching task (trial 4) due to increases in both errors and self-corrections. Name retrieval was also slower on the second shifting task, with many children requiring over 60 seconds to name the color or shape of the 27 designs. Thus, accuracy, speed and efficiency declined as complexity of the tasks increased.

Performance decrements between the two simple naming tasks (trials 1 & 2) may indicate perseverative behavior and impaired inhibitory control. Because this decrement was observed across age groups, it suggests that children as young as 7 years can inhibit a previous naming set and cope with simple conceptual shifts. This finding is consistent with previous developmental studies examining inhibitory control (Becker, Isaac, & Hynd, 1987; Diamond & Goldman-Rakic, 1989; Diamond & Taylor, 1996; Espy, 1997; Gerstadt, Hong & Diamond, 1994; Passler, Isaac, & Hynd, 1985;), as well as with the slowed responses shown by adults in other shifting tasks such as the Stroop Test (Spreen & Strauss, 1991). Alternatively, naming shapes may simply be more difficult, or less well automated, than naming colors for all of the age groups examined in this study.

The 7- and 8-year-olds were less accurate overall than older children. However, the higher self-regulation scores obtained by the younger children were primarily associated with greater rates of errors rather than self-corrections. Differences between the 7- and 8-year-old children and the older age groups were most pronounced on the two-dimensional switching task (trial 4). Given the difficulties exhibited by 7- and 8-year-olds on this task, it is unlikely to be suitable for children younger than 7 years. The 9- to 15-year-old age groups performed similarly on accuracy parameters on trials 1, 2 and 3, while the 14- to 15-year-olds had slightly superior self-regulation scores on the two-dimensional switching task than did younger children.

Strong linear relationships between age and time were found on all four trials, with time decreasing as age increased. The developmental trajectories for time were similar across all trials. The 7- and 8-year-old age groups were significantly slower than the older groups, whereas the mean times for the 9- to 11-year-old age groups were similar but slower than times for the 13- to 15-year-old age groups. Rapid increments in name retrieval between ages 7 to 9 years and again between ages 11 to 13 years are likely to be associated with gains in processing speed and suggest a multi-stage profile of development. Developmental spurts in processing speed may be associated with periods of accelerated growth in the frontal lobe, and may reflect the unfolding and elaboration of connections between the frontal lobe with posterior, temporal and subcortical regions (Hudspeth & Pribram, 1990; Thatcher, 1991).

Girls required less time on the naming tasks and one-dimensional switching task tha boys, whereas mean times for the genders were equivalent on the two-dimensional switchin task. The genders also performed similarly on accuracy parameters across all trials. Thes findings suggest that girls may have an advantage over boys in rapid name retrieval tasks, bu this superiority may diminish when additional cognitive demands are made. Levin an associates (1991) also found that females were superior to males on verbal tasks such as Verb Fluency task and California Verbal Learning Test (CVLT). In contrast, gender differences a rare on non-verbal tasks (Anderson, Anderson, & Lajoie, 1996; Becker, Isaac, & Hynd, 198 Chelune & Baer, 1986; Passler, Isaac, & Hynd, 1985; Welsh, Pennington, & Groisser, 1991; Given the gender differences on the CNT, the gender-based norms may be useful in evaluatin time and efficiency variables, although some cell sizes are small and the gender-specifi normative information should be used cautiously.

In summary, the CNT is suitable for children aged 7 years and older. The normative da demonstrates significant performance advancements with age in both accuracy and spee Accuracy improved dramatically between 7 and 9 years of age and only slightly thereafte whereas speed improved steadily across the age range with spurts between the ages of 7 to years, and 11 to 13 years. The CNT thus appears to be sensitive to functional maturation.

STUDY 2

The aim of this study was to assess the sensitivity of the CNT by administering the test to thr clinical groups and a healthy control group. The clinical groups were comprised of childr with early-treated phenylketonuria (PKU), 31children who had recovered from bacteri meningitis (BM), and survivors of acute lymphoblastic leukemia (ALL). All three clinic groups are at increased risk of cognitive and academic deficits (Anderson *et al.*, 2000, Arnol *et al.*, 1998; Grimwood *et al.*, 2000), including executive dysfunction (Diamond, 1994; Tayl *et al.*, 1987; Taylor *et al.*, 1996; Welsh et al., 1990). The validity of the CNT in measuri brain-related sequelae was examined by comparing each clinical group to the control group, well as by comparison of the clinical groups. The age range of the participants was restricted 12 – 18 years to minimize the developmental factors reported in Study 1, and children we excluded if they had an IQ below 80.

Method

Subjects

The *Phenylketonuria group* (PKU) consisted of 12 early-treated children (4 females, 8 male PKU is an inherited metabolic condition in which the metabolism of phenylalanine (PHE) compromised. Early-treated PKU individuals escape serious brain damage, but at risk cerebral white matter changes (Moats *et al.*, 1999) and neurotransmitter imbalances (Burlina *al.*, 2000). White matter pathology in children with PKU is usually restricted to the posteri periventricular region, however in more extreme cases the changes may extend into frontal a subcortical areas. Cognitive impairments in this population have been identified in the areas

attention (Ris *et al.*, 1994), visuo-motor integration (Brunner, Jordan, & Berry, 1983), processing speed (Burgard *et al.*, 1997; Gourovitch *et al.*, 1994), and executive functioning (Diamond, 1994; Welsh *et al.*, 1990). Eight children in this sample had been treated continuously, while the remaining four children ceased treatment at the ages of 7, 9, 11 and 13 years. All but one child exhibited white matter changes on magnetic resonance imaging (MRI). Group characteristics are presented in Table 6.

The *Bacterial Meningitis group* (BM) consisted of 79 children who had recovered from this disease approximately 12 years earlier (35 females, 44 males). BM is a transient illness associated with significant neurological consequences such as raised intra-cranial pressure, and inflammation of cerebral blood vessels and cranial nerves (Anderson & Taylor, 2000). Cognitive deficits following BM have been reported in the areas of language, visuo-motor coordination, memory and learning, executive functioning and academic achievement (Anderson *et al.*, 1997; Grimwood *et al.*, 2000; Grimwood *et al.*, 1995; Pentland, Anderson, & Wrennall, 2000; Taylor *et al.*, 1996). In this cohort the age at illness ranged from 4 months to 79 months (M = 25.1, SD = 16.1), and 35 children (44%) experienced neurological complications during the acute phase of the illness. Group characteristics are presented in Table 6.

The *Acute Lymphoblastic Leukaemia group* (ALL) included 20 children treated for this disease and in remission since initial treatment (8 females, 12 males). All children received both cranial irradiation (18 Gy) and chemotherapy between 2 and 5 years of age. Cranial irradiation was used to treat childhood ALL for over 25 years, but it is no longer universally employed in treatment protocols. Cranial irradiation is thought to be associated with cerebral white matter changes and subcortical disturbance (Schatz *et al.*, 2000). Neurobehavioural impairments reported in ALL survivors have been found in the areas visuo-motor co-ordination, working memory, shifting attention, and problem solving (eg. Anderson *et al.*, 2000; Brouwers & Poplack, 1985; Taylor *et al.*, 1987). Group characteristics are presented in Table 6.

The *control group* consisted of 79 healthy children from the community (38 females, 41 males). These children were randomly selected from schools, excluding children with a history of developmental, neurological or psychiatric disorder.

Table 6. Demographic Characteristics of Clinical and Control Groups.

Age (years)	PKU	BM	ALL	Control
N	12	79	20	79
Male/Female (%)	67 / 33	56 / 44	60 / 40	52 / 48
Age in years – Mean (SD)	15.0 (2.0)	13.3 (1.4)	13.9 (1.3)	13.5 (1.4)
IQ – Mean (SD)	89.4 (6.1)	97.8 (11.7)	94.7 (9.8)	102.6 (11.0)
SES low/mid/upper (%)	20 / 60 / 20	24 / 64 / 12	40 / 55 / 5	18 / 68 / 14

IQ was assessed using the WISC-III (Wechsler, 1991) and SES was determined Daniel Scale of Occupational Prestige (Daniel, 1983). The clinical and control group differ in terms of gender and SES, however significant differences were identified for IQ ($F(3, 186) = 7.253$, $p < .001$) and age at assessment ($F(3, 186) = 5.304$, $p < .01$). analyses revealed that the PKU group was significantly older than the other three gr that the three clinical groups exhibited significantly lower mean IQs from the contro

Procedure

Children in the clinical groups were identified via hospital database records and i participate in one of several research projects at the Royal Children's Hospital in M All studies were approved by the ethics review board, and informed consent was obta condition of participation. The CNT was administered as part of neuropsycholo batteries and scored according to standardized administration procedures.

Statistical Analyses

Errors, self-corrections, and self-regulation were positively skewed, and therefo differences were analysed using the Kruskal-Wallis test. Although it was not possible analyses to control for age difference between the groups, the normative data pres Study 1 suggest minimal age differences in the frequency of errors and self-correctio the adolescent age range.

Group differences on the time and efficiency parameters, which were distributed, were assessed using 1-way analysis of covariance (ANCOVA). Age was convariate as the PKU group was significantly older than the other groups. IQ was no a covariate in the analyses due to the inter-dependent relationship between the skills by the CNT (e.g. mental flexibility, speed of processing) and general intelligence. Post- were conducted using the Games-Howell test.

Results

All children were able to complete trials 1 and 2. A 15-year-old child in the contr failed to complete trials 3 and 4, while a 12-year-old child in the BM group failed to trial 4.

Errors

As can be observed in Figure 1, the groups did not differ appreciatively in the number committed on trials 1 and 2. No significant between-group differences were found o although the ALL and PKU groups made slightly more errors on this trial in compa the BM and controls groups. However, group differences were found by trial 4 ($\chi^2_3 =$ $p < .001$). Post-hoc analyses revealed that all three clinical groups had significantly high ranks than the control group, and that the ALL group had a higher mean rank than

group ($p < .01$). Total errors also discriminated the groups ($\chi^2_3 = 18.188$, $p < .001$), with significantly higher mean ranks for the ALL and PKU groups than for the BM and control groups.

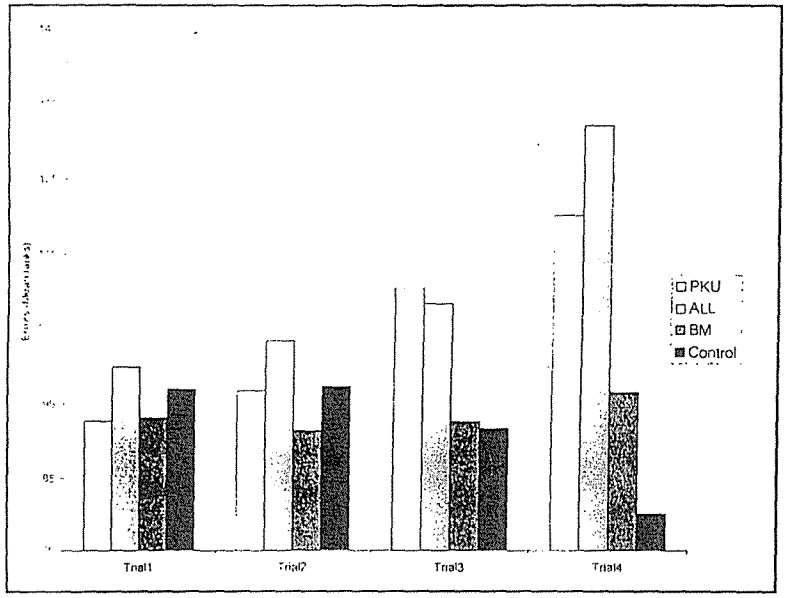


Figure 1. Group mean ranks for errors across the CNT trials.

Self-corrections

Data on self-corrections are presented in Figure 2. Significant group differences in self-corrections were found on trial 2 ($\chi^2_3 = 9.481$, $p < .05$) and trial 4 ($\chi^2_3 = 9.848$, $p < .05$). Post-hoc analyses revealed that the ALL group had significantly lower mean ranks than the PKU, BM and control groups on these trials. Total self-corrections also discriminated the groups ($\chi^2_3 = 14.289$, $p < .01$). Post-hoc analyses again revealed that the ALL group had a lower mean rank than the PKU, BM and control groups. Contrary to expectations, the PKU and BM groups did not make more self-corrections than the control group.

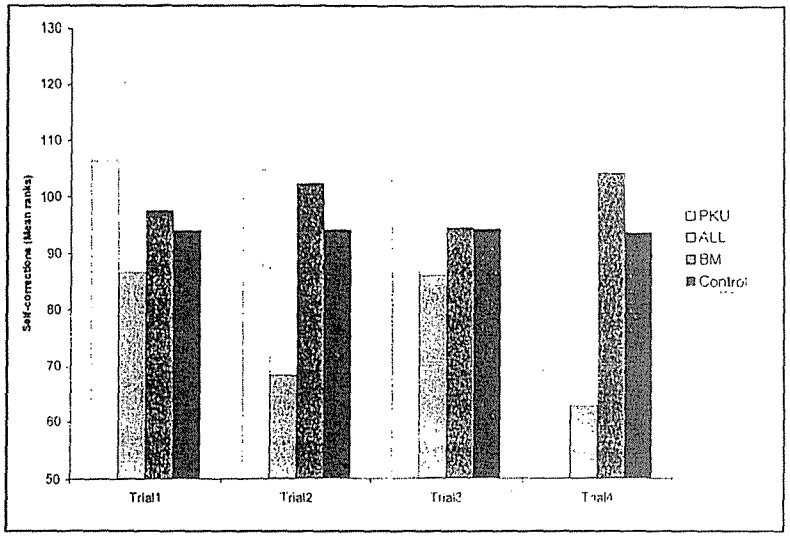


Figure 2. Group mean ranks for self-corrections across the CNT trials.

Self-regulation

Group differences in self-regulation scores were found on trial 4 ($\chi^2_3 = 13.304$, $p < .01$ not on trials 1, 2 or 3 (see Figure 3). Post-hoc analyses revealed that the PKU and ALL g had higher mean ranks than the control group. Similar group differences were found f total self-regulation score ($\chi^2_3 = 8.136$, $p < .05$).

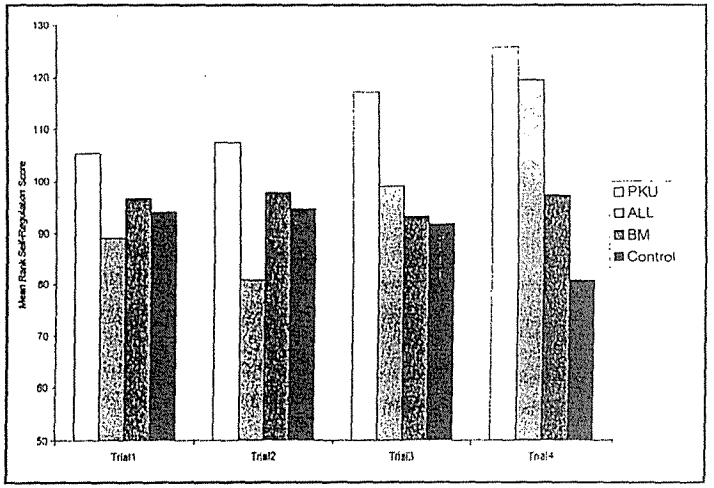


Figure 3. Group mean ranks for self-regulation score across the CNT trials.

Time

Group differences for time were found on trials 1, 3, and 4 (see Figure 4). On trial 1, the ALL and PKU groups took significantly more time than the BM and Control groups ($F(3,185) = 5.528$, $p < .01$). Although no significant group differences were identified on trial 2, the PKU group required an average of 3.5 seconds more to complete the task than the Control group. All four groups required more than double the amount of time taken on trial 2 to complete trial 3. Group differences on trial 3 ($F(3,184) = 9.879$, $p < .001$) and trial 4 ($F(3,183) = 8.712$, $p < .001$) reflected the fact that the PKU group was significantly slower than the ALL, BM and Control groups, while the ALL group required more time than the BM and Control groups. A significant between group difference ($F(3,183) = 9.829$, $p < .001$) was also found for total time. Post-hoc analyses revealed that the PKU group was significantly slower than the other three groups; the ALL group was significantly slower than the BM and Control groups; and the BM and Control groups did not differ.

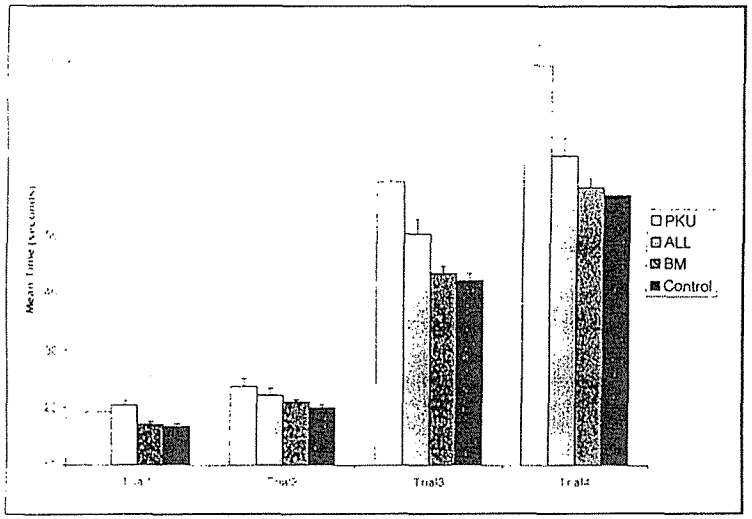


Figure 4. Age adjusted group means and standard error bars for Time across the CNT trials.

Efficiency

Significant group differences on efficiency were found on all trials (see Figure 5). Post-hoc analyses revealed that the PKU and ALL groups were less efficient than the Control group on trial 1, and that the PKU group differed from the Control group on the remaining three trials. The PKU and ALL groups had significantly lower total efficiency scores than the BM and Control groups ($F(3,183) = 8.897$, $p < .001$).

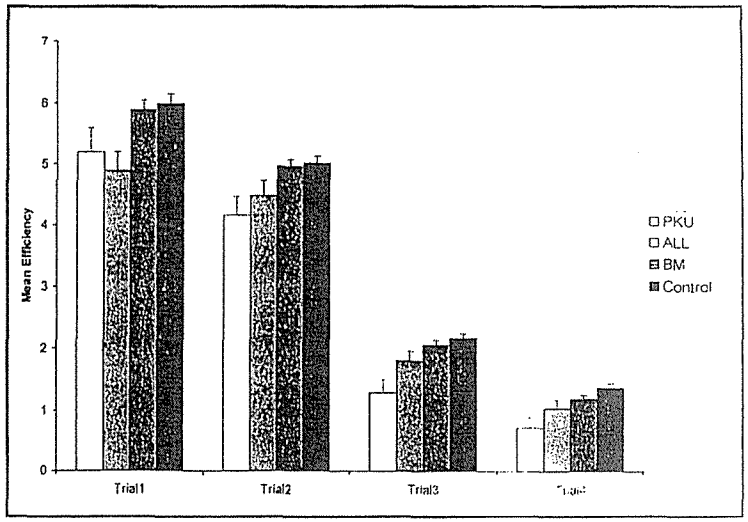


Figure 5. Age adjusted group means and standard error bars for Efficiency across the CNT trials.

Discussion

Despite being significantly older, the PKU group exhibited poorer self-regulation than the control group. On the naming tasks (trials 1 & 2) the PKU group tended to commit more self-corrections, and on the shifting tasks (trials 3 & 4) made significantly more errors. These results suggest that the performance of the PKU group was influenced by both poor self-monitoring and impaired cognitive flexibility. Disinhibition and inflexibility have been reported previously in children with early-treated PKU (Diamond, 1994; Welsh *et al.*, 1990), and are thought to be associated with neurotransmitter imbalances in the prefrontal cortex, such as reduced dopamine levels. White matter pathology is an alternative explanation for the cognitive inflexibility observed in this group, as impaired myelin metabolism is common in individuals with early-treated PKU (Moats *et al.*, 1999) and was present in 11 of the 12 children in this group. Consistent with previous reports of impaired processing speed in children with early-treated PKU (Burgard *et al.*, 1997; Gourovitch *et al.*, 1994), the PKU group was slower to complete both the naming and shifting tasks. For example, by trials 3 and 4 the PKU group was requiring an average of 20 seconds more to complete the task than the control group. The PKU group was less efficient than the control group, which was not surprising given that it made more errors and was slower to complete the trials.

Overall, the ALL group was less accurate than the control group on the CNT. The ALL group made more errors than the control group on the shifting tasks, but performed similarly

on the naming tasks. This group made relatively few self-corrections, suggesting that the high error rate is more likely to reflect inflexibility than disinhibition and poor self-monitoring. Small areas of calcification or necrosis in the basal ganglia as well as white matter pathology, identified in ALL patients treated with cranial irradiation and chemotherapy (Hertzberg *et al.*, 1997; Paakko *et al.*, 1994), may help to explain the inflexibility seen in this cohort. Eslinger and Grattan (1993) proposed that reactive flexibility is dependent on grey matter nuclei in both the basal ganglia and prefrontal cortex, while white matter dysfunction may impact on the connectivity between critical structures. The ALL group was also slower than the control group on both the naming and shifting tasks. Deficits in processing speed have been reported previously in children receiving cranial irradiation (Schatz *et al.*, 2000), and are the most plausible explanation for the slower times observed in the ALL group. Slowed processing may be associated with the myelin abnormalities that are thought to occur in cranially irradiated patients (Hertzberg *et al.*, 1997; Paakko *et al.*, 1994).

The BM group performed similarly to the control group in terms of accuracy on the first three trials, but made significantly more errors on the two-dimensional shifting task (trial 4). The BM group also made more total errors than the control group. In contrast to the PKU and ALL groups, the BM group did not differ from the control group on time or efficiency. Previous research with survivors of BM suggests that children who exhibit neurological complications are at greater risk for cognitive deficits (Grimwood *et al.*, 1996; Taylor *et al.*, 1992), but in this sample children with and without acute neurological complications did not differ on any parameters assessing accuracy or speed.

In summary, the performance of three clinical groups on the CNT differed from a control group, indicating that the CNT is sensitive to cognitive impairment. In comparison to a control group, the PKU and ALL groups were slower and less accurate, while the BM group made significantly more errors on the two-dimensional shifting task. CNT performance also helped to differentiate the 3 clinical groups. The PKU group was significantly slower than the ALL and BM groups on the shifting tasks (trials 3 & 4), the ALL group made the most errors but the least self-corrections, and the BM group performed well on trials 1 to 3 but struggled on trial 4. For adolescents, the naming tasks (trials 1 & 2) were sensitive to deficits in speed of name retrieval, while the shifting tasks, in particular the two-dimensional shifting task, identified group differences in both accuracy and speed.

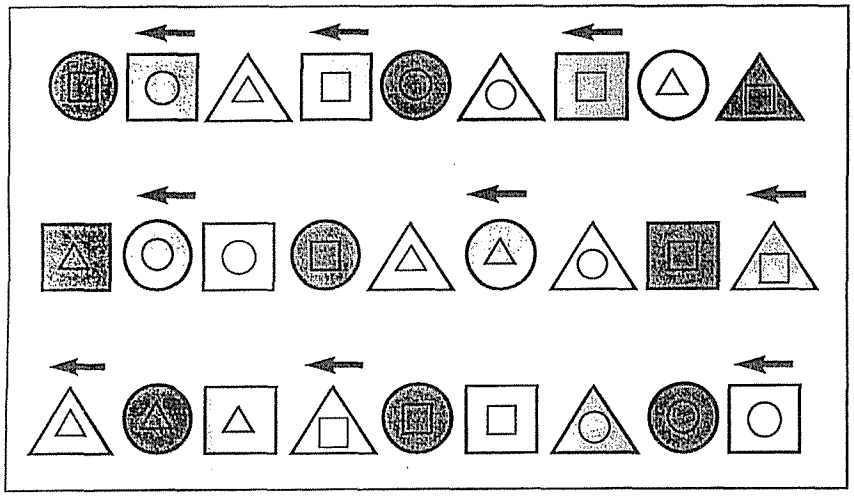
Conclusions

The CNT is a measure of reactive flexibility and speed of name retrieval that can be used as an alternative or adjunct to the Stroop Test (Stroop, 1935), Wisconsin Card Sorting Test (Berg, 1948) and Trail Making Test (Army Individual Test Battery, 1944). Previous research (Grimwood *et al.*, 2000; Mazzocco *et al.*, 1992; Taylor *et al.*, 1998) and findings from Study 2 provide evidence that the CNT is sensitive to brain pathology, although additional validity studies are required with younger age groups and other clinical populations.

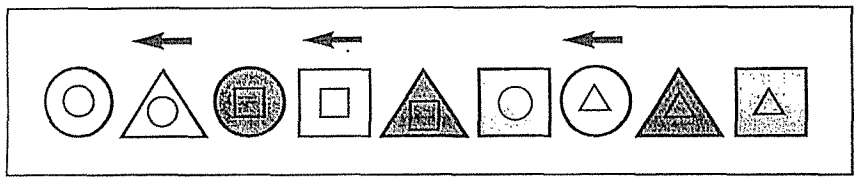
A virtue of the CNT is that it requires only naming of colors and shapes, and is no dependent on literacy competence. The CNT also yields multiple response parameters. Spee of name retrieval can be assessed by time on the naming tasks (trials 1 & 2), whereas accurac can be assessed with the self-regulation score. Both errors and self-corrections are thus take into account. Disinhibition and poor self-monitoring is likely to be associated with recurrin self-corrections, but may also account for a proportion of uncorrected errors. An efficienc score, which rewards both accuracy and speed, was developed to assess cognitive flexibilit Difficulties shifting between altemative rules (i.e. reactive flexibility) is thought to be reflecte by high error rates, slow times and low efficiency on the shifting tasks (trials 3 & 4). Scor reporting contrasts between response parameters were not considered in this paper, but m also be useful for identifying specific processing deficits. Studies of the reliability of the CN response parameters are also required.

The CNT was developed for school-aged children and the normative data from Study indicate that it is sensitive to developmental transitions. However, additional normative studi are required to validate our findings. Our results suggest that the CNT is appropriate for u in school-aged children, although trial 4 may be too complex for children aged 6 years a younger. The Shape School test (Espy, 1997) is likely to be more appropriate for the assessme of simple shifting behaviour in this age range. Ceiling effects on the CNT are unlikely due the nature of response speed, and the inclusion of tasks that vary in complexity. The lat feature makes it suitable across a wide age range and appropriate for a broad spectrum cognitive abilities. The CNT is also relatively quick to administer, especially in comparison the Wisconsin Card Sorting Test.

In conclusion, recent research indicates that the capacity to inhibit behavior develo rapidly in early childhood (Diamond, 1985; Espy, 1997; Espy *et al.*, 1999) and that the abil to shift between conflicting response patterns improves throughout middle childhood a adolescence (Chelune & Baer, 1986; Kelly, 2000; Levin *et al.*, 1991). Valid, reliable a developmentally sensitive measures of reactive flexibility are needed in research and clini practice, especially given the importance of these skills to social competence, acquisition knowledge, and educational achievement. Our findings suggest that the CNT is sensitive developmental delay and cognitive impairment and may thus be useful in meeting these nee



Appendix 1. The CNT stimulus card.



Appendix 2. The CNT practise trial stimulus card.

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