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Rapid Automatized Naming and Gesture by Normal and Language-Impaired Children

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This study investigates whether language-impaired (LI) children show deficits in rapid automatized naming and whether RAN performance is specific to verbal output (or to rapid motor output in general). A total of 67 LI and 54 age-matched control children were tested with the Rapid Automatized Naming (RAN) test (Denckla & Rudel, 1976) and with a manual version of the RAN (RAN-manual) in which subjects were required to provide a nonverbal, pantomime response. Subjects also completed tests of rapid oral and manual sequencing skills and standardized tests of reading ability. Each subject was tested at 4, 6, and 8 years old. The results showed that LI children perform significantly poorer on both versions of the RAN than age-matched controls. Correlations between RAN scores and tests of reading ability were significant for normal and LI subjects and were particularly high for 8-year-old LI children. RAN-manual scores also correlated with 8-year-old LI children's reading scores. Further, RAN and RAN-manual scores for the LI children correlated significantly with these children's manual sequencing abilities, whereas this was not the case for the control subjects. These

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findings suggest that LI children's rapid sequential processing deficits are not limited to verbal output, but also generalize to other motoric domains.

Specific language impairment (LI) refers to children who present with pronounced difficulties of language which cannot be attributed to peripheral impairments (e.g., deafness, abnormalities of vocal tract structures) or to general mental retardation, severe emotional disorder, autism, or focal brain injury (Benton, 1964). Developmental dyslexia is a classification applied to children who have difficulty learning to read or who do not reach expected levels of reading proficiency (Orton, 1937).

While developmental dyslexia and specific language impairment differ in a number of respects, recent research indicates that there may be more overlap between these two disorders than previously suspected. Substantial data indicate that developmental dyslexia does not solely involve deficits in reading, but also involves processes used in other systems, e.g., visual, semantic, and phonological (Ellis, 1984, 1985; Liberman & Shankweiler, 1985; Livingstone, Rosen, Drislane, & Galaburda, 1991; Lovegrove, Garzia, & Nicholson, 1990; Vellutino, 1979). Research investigating adults with a history of developmental dyslexia has revealed specific linguistic deficits which have persisted into adulthood (Kean, 1984; Vellutino, 1979; Whitehouse, 1983). Moreover, longitudinal investigations of children identified as having early LI have shown that these children subsequently show a high incidence of reading difficulty (Aram & Nation, 1975; Hall & Tomlin, 1978; Silva, McGee, & William, 1983; Stark, Bernstein, Condino, Bender, Tallal, & Catts, 1984; Strominger & Bashir, 1977; Tallal & Curtiss, 1990).

One interesting attribute of both language- and reading-impaired children involves deficits in perceptual and motor development, particularly in processing rapid, sequentially presented information. Developmentally dyslexic children are reported to have difficulty maintaining the correct tempo, prosody, and rhythm in their language, reading, writing, and skilled manual actions (Corkin, 1974; Denckla, 1979; Hanes, 1986; Wolff, Michel, & Ovrut, 1990). Dyslexic children also demonstrate difficulty processing temporal sequences in auditory and visual stimuli (Bakker, 1972; Tallal, 1980; Zurif & Carson, 1970). Similarly, Tallal and colleagues have demonstrated marked temporal processing and sequential memory deficits in the nonverbal processing capabilities of LI children (Aten & Davis, 1968; Eisenson, 1966; Lowe & Campbell, 1965; Monsees, 1968; Stark, 1967; Tallal & Piercy, 1973, 1974). These deficits have also been found to correlate significantly with LI children's speech perception and production deficits (Stark & Tallal, 1979; Tallal & Piercy, 1974, 1975; Tallal & Stark, 1981; Tallal, Stark, & Curtiss, 1976).

A rapid processing task which has proven to be highly correlated with developmental reading deficits is the Rapid Automatized Naming (RAN) test (Denckla & Rudel, 1976). This test is based upon the original observations by Geschwind (1965) that there are connections between naming and reading deficits. The RAN test requires subjects to rapidly name serially presented symbols (e.g., letters, numbers, colors, objects), presented randomly in rows along a page. RAN has been shown to reliably distinguish impaired from average readers, as well as dyslexic students from learning-disabled students not presenting with reading difficulties (Denckla & Rudel, 1976; Wolf, Bally, & Morris, 1986).

Surprisingly, little research has addressed RAN performance by LI children. One purpose of the present investigation is therefore to determine whether LI children show characteristic deficits in RAN performance. A second purpose of this investigation is to examine whether deficits in rapid verbal processing found to distinguish normal and LI children (Tallal, Stark, & Mellits, 1985) and to distinguish normal and reading-impaired children (Denckla & Rudel, 1974; 1976) are deficits specific to rapid verbal behavior or to rapid motor behavior in general. In order to answer this question as directly as possible, a new, manual version of the RAN (RAN-manual) was designed. This test maintains the same task requirements of the original RAN, but without the verbal naming component. In the RAN-manual, subjects were required to provide a nonverbal (pantomime) response to a pictured series of objects (e.g., hammer, comb, toothbrush), presented randomly in rows across a page. By comparing the performance of normal and LI children on two RAN tasks which differed primarily in the method of response, (i.e., verbal or manual), it was possible to examine differences in rapid sequencing abilities and the extent to which performance varies as a function of output modality.

In addition, RAN and RAN-manual data were correlated with independent tests of rapid oral and manual sequencing abilities. These comparisons allow an estimate of the extent to which rapid naming tasks involve motor processing skills. The RAN data were also correlated with standardized tests of reading ability (Gates–MacGinitie Reading Test, 1964; Gates–McKillop–Horowitz Reading Diagnostic Test, 1981) in order to estimate the extent to which RAN and RAN-manual scores correspond with reading abilities. Finally, in order to determine whether different strategies are used as children mature, we employed a repeated measures design spanning critical years of language and early reading development (ages 4 to 8 years).

METHOD

Subjects

Subjects were children who completed all 5 years of the San Diego Longitudinal Study (SDLS), "Evaluation of the Outcomes of Preschool Disorders of Language" (Tallal, Curtiss,

& Kaplan, 1988). These children were tested with a comprehensive series of neuropsychological and linguistic tests to determine whether they demonstrated language impairment, speech neuromuscular difficulties, or known predisposing conditions which might result in cognitive or neurological deficits (see Ziegler, Tallal, & Curtiss, 1990, for a detailed description of subject selection procedures). From a total of 149 children inducted at the inception of the 5-year longitudinal study at age 4 years, 121 children successfully completed all 5 years. This group included 67 LI children and 54 age-matched, language-normal (LN) controls. The LN group included 28 boys and 26 girls, and the LI group 48 boys and 19 girls. At induction, the two groups were closely matched for age (LN, $X = 4.39$ years, $SD = .28$; LI, $X = 4.34$ years, $SD = .28$) and performance (nonverbal) IQ (LN, $X = 111.8$, $SD = 7.8$; LI, $X = 109.4$, $SD = 11.9$).

All subjects had normal hearing acuity, no motor handicaps, no oral structural or motor impairments affecting movements of the articulators, and no middle ear pathology or history of chronic middle ear disease. All subjects came from a monolingual background and there were no racial differences between groups. In order to qualify as a LI subject, children were required to meet the following criteria at induction:

1. A nonverbal performance IQ of 85 or better on the Leiter International Performance Scale (Leiter, 1940).
2. Test scores at least 1 year below both performance mental age and chronological age on a battery of expressive and receptive language tests.
3. Language skills equal to or greater than those expected at 1 year of normal development.
4. No obvious signs of infantile autism or emotional difficulties.

Age-matched, LN subjects were selected based upon the following criteria:

1. A nonverbal performance IQ of 85 or better (and not greater than the highest IQ demonstrated by a LI subject) on the Leiter International Performance Scale.
2. Test scores not more than 6 months below performance mental age and chronological age for a battery of expressive and receptive language tests.
3. Speech articulation age not more than 6 months below chronological age.
4. No emotional or neurological problems.

Demographic and test performance data for the LI and LN groups are shown in Table 1.

Materials

Rapid automatized naming. Rapid naming capabilities were tested using materials and procedures adapted from the RAN test (Denckla & Rudel, 1976). In order to increase the probability of subjects (especially young LI subjects) knowing the names of the pictures, the RAN objects subtest developed for young children was used. These pictures were STAR, CHAIR, HAND, DOG, and BOOK.

In order to test rapid, nonverbal identification of pictures, a nonverbal equivalent to the RAN (RAN-manual) was developed. In the RAN-manual, subjects responded by pantomiming the functional use of objects. Pictures of the following five objects were used: HAMMER, TOOTHBRUSH, COMB, FORK, BALL.

Manual skills, oral motor skills, and reading ability. Manual tasks included finger opposition (Touwen & Prechtl, 1970) and coins-in-the-box (Doll, 1946). Measures of speech oral motor fluency included single-syllable and a multiple-syllable diadochokinesis (DDK) tasks, and Rapid Word Production (RWP). The two diadochokinesis measures were originally designed to investigate differences in the motoric events involved in single utterance and rapidly alternating utterance production (see Kimura, 1979; Kimura & Watson, 1989; Wolff, Cohen, & Drake, 1984).

TABLE 1
DEMOGRAPHIC AND TEST PERFORMANCE DATA FOR LANGUAGE-NORMAL (LN) AND LANGUAGE-IMPAIRED (LI) GROUPS

	LN		LI		
Total subjects:	54		67		
Boys:	28		48		
Girls:	26		19		
	M	*SD*	*M*	*SD*	*p*
Race					
Caucasian	47	—	61	—	ns
Other (Black, Hispanic, Asian)	7	—	6	—	ns
Leiter IQ (Leiter, 1940)	112	8	109	12	ns
SES (low, medium, high ranges)	2.4	0.8	3.1	1.0	ns
Age at induction	4.4	0.3	4.4	0.3	ns
Mean language age	4.6	0.6	3.1	0.5	*
Combined receptive language measures	4.4	0.5	3.2	0.6	*
Sequenced Inventory of Communicative Development	3.8	0.2	3.2	0.5	*
Northwest Syntax Screening Test	4.7	0.9	3.3	0.6	*
Token Test	4.9	1.4	3.0	0.6	*
Combined expressive language measures	4.7	0.6	3.0	0.3	*
Sequenced Inventory of Communicative Development	3.9	0.2	2.8	0.4	*
Northwest Syntax Screening Test	4.8	0.9	3.0	0.1	*
Carrow Elicited Language Inventory	5.4	0.8	3.1	0.3	*

* $p < .001$ for LI versus LN groups.

Procedure

Subjects were tested individually in a quiet room. The RAN-verbal and RAN-manual test sessions took approximately 5–10 min each, while the battery of manual skills, oral motor skills, and reading tests took approximately an hour to complete. The order of RAN stimulus presentation (verbal, manual) was counterbalanced. In order to obtain developmental data, each subject was tested at three data points (at 4, 6, and 8 years old). Reading data were obtained for children at the second and third data points.

RAN. Subjects were shown five different pictures presented randomly in rows along a page. Each testing session began with a training procedure. The subject was shown a single row of pictures which were named by the examiner. Next, the child was asked to name each picture in the row. If a subject named a picture incorrectly while practicing the first row, he/she was told the correct name. Subjects who failed to name any picture in the first row were allowed to practice naming a second row. If a subject failed to name all pictures correctly in this row, the task was discontinued. This was a simple task that was easily mastered by the children. In the test trials, subjects were given a new page containing the same pictures presented randomly in rows filling the entire page (80 objects total). A manila folder with a cut-out segment that revealed only a single row at a time was used to minimize confusion. As soon as the child correctly named the final picture in each row, the experimenter moved the folder to the next row. Subjects were instructed to name the pictures on the page as quickly as possible. The numbers of correct and incorrect productions made in a 60-sec period were recorded. A production was scored correct if it was the proper lexical item matched to the target. Children were not penalized for phonological or articulation errors.

RAN-manual. The procedure was identical to that used for the RAN test, except that instead of producing names for pictures, subjects were required to produce pantomimed motor responses demonstrating the function rather than the name of each object. Subjects were trained to produce a stylized pantomime response to each object and were warned against making more elaborate responses which might require more time (i.e., two and only two bangs for the hammer). Subjects completed two rows of practice trial to assure their learning of the required responses before proceeding to the timed trials. Because the task used common, easily learned gestures and required only a few minutes for completion, children mastered the task quickly.

Finger opposition. Subjects were seated at a table facing the examiner. A pretest was administered in which the examiner modeled a finger touching pattern, touching each finger of the right hand with the right thumb (following a sequence of touches from index to little finger and back again). The task was demonstrated for each subject several times. The examiner then watched the child complete the task until it was clear that the task was completely understood. Subjects were then instructed to repeatedly perform this motor sequence as fast as possible, and a 15-sec test trial was begun. Subjects used their preferred hand. The examiner scored the number of successful cycles. Errors were considered: (1) touching the same finger twice, (2) missing a finger in a sequence, (3) changing direction before completing one sequence of index to little finger or the reverse.

Coins-in-the-box. Subjects were seated at a table facing the examiner. Between the child and a small wooden box, 20 pennies were lined up in two rows of 10 pennies each. The child was instructed to pick up the pennies one at a time and place them in the box as fast as possible. One trial of 15 sec was given. The experimenter recorded the hand preferred by the child for the task and the number of pennies successfully deposited in the box.

Diadochokinesis (DDK). Rapid stimulus repetition was modeled for the subjects by the examiner, and subjects were then required to repeat a stimulus as rapidly as possible over a 5-sec period. This was first done for the *single-syllable* stimulus /pa/, followed by /ta/, and finally /ka/. Subjects were next asked to produce *multiple-syllable* stimuli (sequenced series of the syllables /pa/, /ta/, /ka/) over a 15-sec period. Subjects' productions were tape recorded for subsequent analysis and scoring. The numbers of items correctly produced within the timed period of each trial were recorded. For the multisyllabic series, a completed series of three syllables was scored as a single correct response.

Rapid word production (RWP). Children were asked to repeat a polysyllabic word three times, after a model set by the experimenter. There were five target words, two to five syllables in length (kitty, buttercup, cafeteria, refrigerator, television). Subjects' responses were tape-recorded and later transcribed in broad transcription. Points were given for each correctly pronounced syllable. Errors were classified as word substitutions, phonemic errors, or phonetic errors. The amount of time taken to repeat each polysyllabic word three times was also recorded.

Reading tests. The Gates–MacGinitie Reading Test (1964) was administered in order to assess vocabulary and comprehension skills. For the purpose of assessing decoding (i.e., reading nonsense words), children were given the Gates–McKillop–Horowitz Reading Test (1981). Combined scores were calculated based upon subjects' achievement on the vocabulary, comprehension, and decoding sections of the two exams. Data were obtained for children at the second and third data points (i.e., at ages 6 and 8 years old).

RESULTS

Rapid Automatized Naming

Of the 726 total test scores (121 subjects × 2 tests × 3 data points) there were only 7 instances (=1%) of missing data. For these cases, imputed values were utilized in further analyses requiring equal numbers of cells. Imputed values were derived from regression data considering Group and Stimulus factors.

The key dependent variable investigated was subjects' speed of response, defined as the total number of attempts made in the 60-sec experimental trial period. The data were analyzed statistically by means of a three-way (Group × Age × Test) analysis of variance (ANOVA), with Age and Test (verbal, manual) designated as repeated measures. The results are shown graphically in Fig. 1. A number of statistically significant patterns were observed. There was a significant main effect for Group [$F(1, 116) = 23.4$, $p < .001$], with LN subjects performing better than LI subjects. A significant main effect for Age [$F(2, 232) = 276.9$, $p < .001$] indicated that children performed more rapidly with maturation. There was also a significant main effect for Test [$F(1, 116) = 614.9$, $p < .001$], indicating quicker performance on the RAN-verbal than the RAN-manual test. A significant Test × Age interaction [$F(2, 232) = 49.4$, $p < .001$] indicated that, with maturation, subjects performed proportionately quicker on the RAN-verbal test than the RAN-manual test. Post-hoc tests indicated, however, that for both versions of the RAN there was significant improvement with maturation (i.e., from age 4 to 6, and from age 6 to 8). Last, there was a significant Group × Test interaction [$F(1, 116) = 11.8$, $p < .001$], indicating a proportionately greater difference in group scores for the RAN than for the RAN-manual. Nevertheless, post-hoc scores of this interaction showed that on both versions of the RAN, LI children performed significantly slower than LN children. Additional anal-

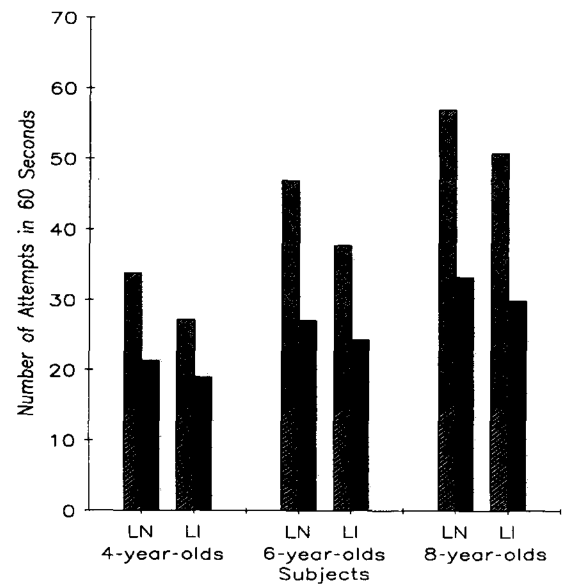

FIG. 1. RAN-verbal (shaded bars) and RAN-manual (solid bars) speed of performance. Data for language-normal (LN) and language-impaired (LI) children tested at ages 4, 6, and 8 years old.

yses revealed that this interaction was independent of subjects' performance on tests of manual skills, suggesting that LI children's impairment on the RAN-manual is not simply the result of general clumsiness.

A second analysis investigated subjects' accuracy (defined as the total number of attempts minus the number of incorrect responses, divided by the total number of attempts). These data, shown in Fig. 2, indicate that accuracy was generally high, ranging from a low of 84% correct (4-year-old, LI, RAN-manual) to a high of 99% (8-year-old, LN, RAN-manual).

The data were investigated statistically by first conducting regression analyses partialling out the number attempted from the number of incorrect responses. The results of the regression analysis indicated that the number attempted did not factor into the percentage accuracy results. A three-way (Group × Age × Test) ANOVA was then conducted using accuracy as the dependent measure. A number of statistically significant patterns were observed. A significant main effect for Group [$F(1, 119) = 11.3$, $p < .001$] shows that LN children are more accurate than LI children. A significant main effect for Age [$F(2, 238) = 14.9$, $p < .001$] is attributable to increasing accuracy with maturation, with a particularly large increase between ages 4 and 6. A significant main effect for Test [$F(1, 119) = 14.8$, $p < .001$] indicates that subjects were more accurate on the RAN-verbal than the RAN-manual test. There was a significant

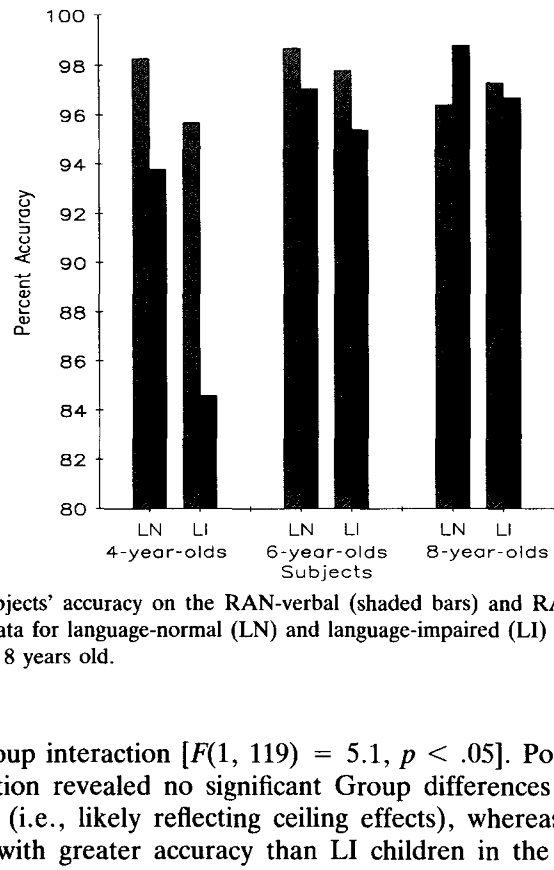

FIG. 2. Subjects' accuracy on the RAN-verbal (shaded bars) and RAN-manual (solid bars) tasks. Data for language-normal (LN) and language-impaired (LI) children tested at ages 4, 6, and 8 years old.

Test × Group interaction [$F(1, 119) = 5.1$, $p < .05$]. Post-hoc tests of this interaction revealed no significant Group differences in the RAN-verbal data (i.e., likely reflecting ceiling effects), whereas LN children performed with greater accuracy than LI children in the RAN-manual data. There was a significant Age × Group interaction [$F(2, 238) = 5.4$, $p < .01$]. Post-hoc tests of this interaction showed that at age 4, LI children were significantly less accurate than their age-matched controls. Moreover, LI children were significantly less accurate at age 4 than they were at ages 6 and 8 years. A significant Test × Age interaction [$F(2, 238) = 14.6$, $p < .001$] demonstrates that the main effect for Age pertains chiefly to the RAN-manual data. Post-hoc tests showed significantly lower accuracy for 4-year-old children's RAN-manual data than for their RAN-verbal data.

In summary, the statistically significant patterns observed in the RAN-verbal data also were obtained for the RAN-manual data. Thus, for children tested at each of the three ages, the RAN-manual test distinguished LI and LN performance in a manner similar to the RAN-verbal test. Although the RAN-manual task took slightly longer to complete than the RAN-verbal, both tests showed that children perform more rapidly with maturation. Critically, it was found that at ages 4, 6, and 8 years, LI children are slower than LN children on both the RAN-verbal and the RAN-manual tests. An analysis of subjects' accuracy revealed overall high performance in this task. While no group differences in accuracy were noted in the RAN-verbal data, in the RAN-manual data LI subjects were less accurate than their LN controls. Post-hoc analysis showed that this group difference in RAN-manual scores was due primarily to low scores by LI 4-year-olds.

Manual, Oral Motor, Reading Skills

Subjects' mean scores and standard deviations are listed for each manual, oral motor, and reading test in Table 2. As stated earlier, reading tests were not given to the 4-year-old children. In addition, due to procedural errors a number of 4-year-old children did not take the Rapid Word Production test. This was particularly true for LI 4-year-old children ($n = 37$). For the five oral motor variables listed in Table 2, a small percentage of the data (0.6%) contain imputed values. This was done in order to maximize data available for longitudinal analysis. Imputed scores were calculated using regression formulae based upon Group values.

The data in Table 2 show that performance of LN subjects was superior to that of LI children and that children's performance increased with age. To evaluate these data statistically, separate two-way (Group × Test) ANOVAs were computed for each age group.[1] The results showed main effects for Group and Test, as well as Group × Test interactions, all significant at $p < .01$. Post-hoc analyses of the Group × Test interactions were conducted in order to compare, for each test, the performance of LN and LI children. These results are summarized in Table 3. Overall, LN children's scores were statistically greater than those of the LI children. Group differences were most pronounced in the oral motor tests, with the multiple-syllable DDK test demonstrating the most consistent group differences at each of the three age groups. The manual test data were less consistent, with finger opposition showing group differences for 4- and 8-year-olds, and coins-in-the-box failing to reach significance at any of the three data points.

A second series of post-hoc tests was computed in order to compare, for each age group, single-syllable and multiple-syllable DDK scores. The results indicate that single-syllable DDK scores were superior to multiple-syllable scores. This was statistically significant for both Groups at age 4 and age 6, and for LI subjects at age 8.

Pearson product-moment correlations were calculated to assess the relationship between performance on the oral and manual motoric tests and

[1] Three two-way (Group × Test) ANOVAs were used instead of one three-way (Group × Test × Age) ANOVA because (1) main effects of Age were not of critical interest, and (2) the three-way, repeated measures design would be limited by a small n, i.e., that of LI 4-year-old subjects.

TABLE 2
MEAN AND STANDARD DEVIATION SCORES FOR LANGUAGE-NORMAL (LN) AND LANGUAGE-IMPAIRED (LI) SUBJECTS

		LN			LI		
Age in years:		4	6	8	4	6	8
Oral motor							
DDK single-syllable	Mean	44.8	59.1	64.2	35.6	50.7	57.8
	SD	9.6	9.9	15.0	12.6	11.9	13.6
DDK multiple-syllable	Mean	24.3	46.0	61.8	7.7	19.1	46.1
	SD	20.5	19.3	17.3	13.4	22.0	24.7
Rapid word production	Mean	49.7	54.8	55.8	28.7	45.2	51.0
	SD	7.1	3.8	2.3	11.0	10.2	7.2
Manual							
Finger opposition	Mean	24.5	39.5	56.6	15.7	36.2	47.6
	SD	11.6	10.6	15.9	13.7	14.9	17.0
Coin-in-the-box	Mean	39.4	50.6	55.6	34.5	44.9	53.8
	SD	10.3	10.5	12.6	9.9	11.9	13.5
Reading							
Composite	Mean	NA	20.5	68.2	NA	7.5	37.7
	SD		20.5	30.2		12.1	23.5

TABLE 3
SIGNIFICANCE LEVELS OF NEWMAN–KEULS POST-HOC TESTS EXAMINING GROUP DIFFERENCES IN ORAL MOTOR AND MANUAL SKILLS

	Oral motor			Manual	
	DDK single-syllable	DDK multiple-syllable	Rapid word production	Finger opposition	Coins-in-the-box
Age (years)					
4	.01	.01	.01	.01	ns
6	.01	.01	.01	ns	ns
8	.05	.01	ns	.01	ns

the RAN tests. For these correlations, a measure was derived for the RAN data which incorporated both speed and accuracy information. This measure, percentage correct, was defined as the total number of attempts minus the number of incorrect responses, divided by 80 (the total number of possible responses per test type). The data are presented in Table 4. Due to the number of correlations, an alpha level of $p < .01$ was set for statistical significance in order to reduce the possibility of Type 1 errors.

The data (Table 4) indicate that for the LN group, with a single exception, only weak (often negative) correlations obtained. Correlations between the motoric tests and the RAN-verbal ranged from a low of $r = -.05$ (coins-in-the-box, age 4) to $r = .39$, $p < .01$ (DDK, multiple-syllable, age 6). Correlations between RAN-manual and motoric test performance were even lower, with none reaching significance.

Correlations between the RAN tests and oral and manual skills were considerably higher for the LI group, with several correlations proving highly significant. Correlations with RAN-verbal ranged from a low of $r = -.02$, the only negative correlation (rapid word production, age 8), to a high of $r = .44$ (finger opposition, age 4). Several other motoric variables were significantly correlated with RAN-verbal performance by the LI group (coins-in-the-box, age 4; DDK multiple-syllable, age 6; coins-in-the-box, age 6; DDK, multiple-syllable, age 8; coins-in-the-box, age 8). Even higher correlations were found between the performance of the LI children on motoric skills and RAN-manual. The correlation between coins-in-the-box, age 4, and RAN-manual performance was highly significant ($r = .57$, $p < .005$), as was finger opposition, age 4 ($r = .52$, $p < .005$). Other significant correlations included: finger opposition, age 6; and coins-in-the-box, ages 6 and 8.

Pearson product-moment correlations were calculated to assess the relationship between reading and RAN speed of performance (see Table 4). Reading was assessed in this study at ages 6 and 8 years. For the LN

TABLE 4

PEARSON PRODUCT-MOMENT CORRELATIONS BETWEEN ORAL MOTOR, MANUAL, AND READING TESTS AND RAN-VERBAL (V) AND RAN-MANUAL (M) SPEED OF PERFORMANCE

	LN						LI					
Age in years	4 $n = 49$		6 $n = 53$		8 $n = 54$		4 $n = 37$		6 $n = 65$		8 $n = 66$	
Oral motor												
Test type	V	M	V	M	V	M	V	M	V	M	V	M
DDK single-syllable	.34	.01	.09	.11	−.13	.01	.36	.15	.21	.14	.03	.20
DDK multiple-syllable	.31	−.15	.39*	.16	.21	−.04	.19	.22	.34*	.10	.29	.11
Rapid word production	−.02	−.34	.04	.15	.12	.16	.12	.24	.11	.10	−.02	.23
Manual												
Finger opposition	.23	.06	.15	.13	.31	−.03	.44*	.52**	.16	.34*	.11	.17
Coin-in-box	−.05	.06	.15	.24	.13	.09	.34	.57**	.39**	.31*	.34*	.33*
Reading												
Composite	—	—	.36*	.05	.36*	.08	—	—	.36*	.19	.64**	.32*

Note. Data are for language-normal (LN) and language-impaired (LI) subjects at age 4, 6, and 8 years.

* $p < .01$.

** $p < .005$.

group, significant correlations were obtained between reading scores and RAN-verbal performance at age 6 ($r = .36$, $p < .01$) and at age 8 ($r = .36$, $p < .01$). Correlations between reading and RAN-manual performance were not statistically significant at either age. A somewhat different pattern was obtained for the LI group. At age 6, reading scores and RAN-verbal performance were significantly correlated ($r = .36$, $p < .01$), while reading scores and RAN-manual were not ($r = .19$). This pattern is similar to the age 6 LN data. For 8-year-old LI children, however, the correlation between reading and RAN-verbal performance was highly significant ($r = .64$, $p < .005$), and RAN-manual and reading scores were also significantly correlated ($r = .32$, $p < .01$). Taken together, these correlations suggest that RAN-manual is a less sensitive predictor of reading ability than the RAN-verbal and that RAN tests are more sensitive indicators of lowered reading abilities for 8-year-old than for 6-year-old children.

DISCUSSION

The key findings of these experiments can be summarized as follows. LI children who began the study at age 4 were subsequently found to be severely reading impaired at ages 6 and 8 years. Test scores on the RAN-verbal and RAN-manual indicated that LI children had completed significantly fewer items per unit time than normal, age- and IQ-matched controls. Although this effect was slightly stronger in the RAN-verbal than the RAN-manual data, the pattern was statistically significant for both versions of the test at all data points (i.e., at ages 4, 6, and 8 years old). In addition to being slower on the RAN, LI children (particularly 4-year-olds) were less accurate. Four-year-old LI children made more mistakes than their age-matched controls, especially in the RAN-manual. Comparison of RAN scores and tests of reading performance, assessed at ages 6 and 8 years old, revealed significant correlations between RAN-verbal and reading scores at both ages. The strength of these correlations increased with age for the LI children, but not for the LN children. Correlations between RAN-manual and reading test scores were significant for the 8-year-old LI children. LI and LN children differed significantly on tests of oral motor skills and to a lesser extent on tests of manual motor skills. Correlation of RAN scores and tests of motor skills showed little relationship between RAN and oral motor function, while a number of significant correlations were noted between RAN scores and tests of manual skills. Manual skills were significantly correlated with RAN scores for the LI children, but not for the LN children.

The finding that 4-year-old LI children show severe reading difficulties at ages 6 and 8 is further evidence that children identified as having early language impairment show a high incidence of subsequent reading difficulty. Moreover, the fact that LI children were significantly impaired on the RAN indicates that previous reports of RAN deficits in reading-impaired children also hold true for children with developmental language impairment. Because the RAN test requires rapid, sequential processing, these data add support to the hypothesis that disability in perceiving or producing rapid, sequential information is a consistent correlate of developmental language and reading disorders (Tallal & Piercy, 1974, 1975; Tallal et al., 1976; Stark & Tallal, 1979; Tallal & Stark, 1981). However, as pointed out by Rees (1981) and Johnston (1988), it is not yet possible to establish whether this link is causal or merely correlational.

While tentative, the results of the verbal and manual RAN tests address the extent to which RAN performance generalizes to other neuromotor domains. The fact that the RAN-manual test distinguishes normal performance from LI children's performance suggests that speech motor processes are not critical components of RAN performance. Rather, LI children's difficulty with both forms of the RAN may reflect impairment with processes not strictly linked to verbal output (e.g., stimulus detection, semantic representation, or short-term memory). It is important to emphasize that semantic representation, memory, and perceptuomotor processes were involved in both versions of the RAN given in this study. Thus, deficits in each may have contributed to the pattern of results found in the LI vs. LN children. Moreover, in order to construct a complete model of RAN processing, it is critical to compare LI children's performance with that of language-matched (i.e., younger) controls. Lacking this information, it is difficult to determine whether the depressed scores of LI children are due to language-dependent or general developmental factors.

The oral and manual skills data indicated that LI children's scores were generally lower than those of the LN subjects. Group differences were most pronounced for the oral motor tests and for finger opposition, while the manual test coins-in-the-box showed no significant group differences. These data replicate the finding of Tallal et al. (1985) that oral motor skills are an important predictor of specific language impairment. The data also suggest that this relationship is strongest during early stages of language impairment (i.e., at ages 4 and 6 years), becoming less predictive by age 8.

When the oral and manual skills data were correlated with RAN scores, the results for normal children showed little relationship between RAN (verbal or manual) performance and performance on the motoric tasks. However, there were a number of significant correlations for the LI group. LI children's manual test results correlated significantly with their RAN scores (verbal and manual), whereas correlations between oral motor data and RAN scores reached significance only in one case.

The fact that manual (and not oral) skills correlated with LI children's RAN scores supports the notion that speech production skills do not critically distinguish normal from LI children's RAN performance. Rather, these data suggest that shared processing constraints influence both rapid manual skills and rapid word naming. For example, manual sequencing and RAN tasks may both involve less overlearned and less frequently used processes than those involved in oral motor tasks. That is, the rapid, manual movement tasks and the rapid processing demands of the RAN may constitute relatively complex, controlled forms of motor behavior which are not likely to become easily automatized. In contrast, the production of rapid, sequential syllables in the oral motor tasks may recruit motor processes similar to those commonly used by subjects (e.g., during rapid speech). If this reasoning is correct, then it might be inferred that LI children have greater difficulty with the controlled processing aspects of naming tasks. The distinction between automatic and controlled processing has been useful in investigations of LI children's memory deficits (Ceci, 1982, 1983). Future research should address these issues.

One additional point of interest deserves special note. Although LI children were slower than LN children on both the single-syllable and the multiple-syllable DDK tasks, group differences were much greater in the multiple-syllable task. These findings may be related to recent theories of brain localization for speech production. Kimura (1979) and Kimura and Watson (1989) have proposed that predominantly anterior brain structures are involved in the production of single-syllable DDK stimuli, whereas posterior brain structures are more involved with the production of multiple-syllable stimuli. The data with LI children reported here replicate the findings with dyslexic subjects (Wolff et al., 1984) that greater impairment may be found for multiple-syllable than for single-syllable DDK tasks. Viewed in the theoretical framework of Kimura and colleagues, the current behavioral data implicate posterior brain structures. Indeed, magnetic resonance imaging results from a recent study, in which images were obtained from a subset of the subjects participating in the current study, revealed significantly reduced volume in the left posterior perisylvian region of the cerebral cortex in LI children compared to that in matched control children, and reduced volume in homologous structures in the right hemisphere (Jernigan, Tallal, & Hesselink, 1987; Jernigan, Hesselink, Sowell, & Tallal, 1990). Future studies relating behavioral data directly to neuroanatomical information should help to clarify these hypotheses.

In conclusion, it was determined that LI children show RAN deficits in both verbal naming tasks and tasks which require a manual response. Although the present data do not allow for a complete model of RAN processing, the findings are consistent with the notion of a possible common deficit underlying both language impairment and developmental dyslexia; namely, impairment with rapid, serial behavior in timed identification (naming, pantomime) tasks. Additional experimentation should be conducted to clarify the exact processes (e.g., perceptual, phonological, memory-related, motoric) involved in this deficit.

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