CALLOSAL TRANSFER IN DIFFERENT SUBTYPES
OF DEVELOPMENTAL DYSLEXIA

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ABSTRACT

Sixteen controls (age 6-13) and 20 native Italian children with developmental dyslexia
(age 7-15) received a test of callosal transfer of tactile information. Among the dyslexic
children, 7 had a diagnosis of L-type, 7 of P-type and 6 of M-type dyslexia according to
Bakker’s classification. Both control children and children with dyslexia made a
significantly larger number of errors in the crossed localization condition (implying callosal
transfer of tactile information) vs. the uncrossed condition. In the same condition, children
with dyslexia made a significantly larger number of errors than controls. In the crossed
localization condition L-types and M-types made a significantly larger number of errors
than P-types and controls, while there was no significant difference in performance between
P-types and controls. These findings are discussed in terms of defective callosal transfer or
deficient somatosensory representation in children with L- and M-dyslexia.

Key words: subtypes of developmental dyslexia, corpus callosum, callosal transfer,
tactile information

INTRODUCTION

Anatomical and electrophysiological studies show that myelination of the
corpus callosum is not complete until the end of the first decade of life
(Yakovlev and Lecours, 1967; Salamy, 1978; Giedd, Rumsey, Castellanos et al.,
1996; Giedd, Blumenthal, Jeffries et al., 1999). So far, several behavioral studies
carried out on children have aimed at verifying whether – at functional level, too
– inter-hemispheric transfer of information improves with age.

One of the most widely applied methods to assess development of inter-
hemispheric transfer is the study of tactile information transfer. A relatively
simple method consists in the assessment of the capacity of a blindfolded subject
to indicate (with the thumb) another stimulated finger in two different
conditions: an uncrossed localization condition in which the subject responds by
touching with the thumb the finger stimulated by the examiner, and a crossed
localization condition in which the subject responds with the hand contralateral

Since there are no direct callosal connections between the somatosensory
cortices of the two hemispheres receiving tactile afferences from the hands (cf.
Brodal, 1981), the capacity to perform a crossed localization task (responding by
touching, for example, the index finger of the right hand following stimulation

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of the index finger of the left hand) presupposes that (a) the primary sensory area (SI) of the right parietal cortex receives tactile afferences from the stimulated left hand; (b) tactile information is projected to the somatosensory association areas of the same hemisphere; (c) information is transferred through the corpus callosum to the posterior parietal association area of the opposite hemisphere; and (d) information is projected to the motor cortex of the left hemisphere while the response is being made with the right hand (Quinn and Geffen, 1986).

Normal adults have been shown to be 7% poorer in the crossed localization condition than in the condition implying a response with the same stimulated hand (uncrossed localization) (Geffen, Nilsson, Quinn et al., 1985). Studies on children have shown that the capacity to transfer information through the corpus callosum increases with age. Children aged 5-6 years tend to make a significantly larger number of errors in the crossed localization condition (approximately 27% incorrect responses) than in the uncrossed localization condition (5% incorrect responses). Gradually, the error percentage decreases and in the crossed localization condition the percentage of errors made by children aged 9 and 11 years is similar to that of adults (crossed-condition: 11% and 9% incorrect responses, respectively; uncrossed-condition, approx. 2% in both groups) (Galín, Diamond and Herron, 1977; Quinn and Geffen, 198). A more recent study on callosal transfer of tactile information, though revealing a larger number of errors in the crossed localization condition, did not find significant differences across groups of children aged 6, 8, and 10 years (Pipe, 1991).

Several neuroimaging studies have highlighted an abnormal size of some portions of the corpus callosum in subjects with developmental dyslexia (Beaton, 1997; Duara, Kushch, Gross-Glenn et al., 1991; Hynd, Hall, Novey et al., 1995; Rumsey, Casanova, Mannheim et al., 1996; Robichon and Habib, 1998). Some behavioral studies on children with developmental dyslexia suggest that defective inter-hemispheric integration and/or inter-hemispheric transfer of information play an important role in reading disorders. Indeed, tachistoscopic investigations (Gross-Glenn and Rothenberg, 1984), dichotic listening tests (Beaumont, Thompson and Rugg, 1981; Fabbro, Mammano, Paci et al., 1987) and bimanual motor coordination tasks (Gladstone, Best and Davidson, 1989; Wennekes and Njiokiktjien, 1991) have shown an abnormal transfer of sensory information in children with dyslexia. Studies assessing callosal transfer of tactile perceptual information have revealed significant deficits in dyslexic children (Fletcher, Taylor, Morris et al., 1982; Gross-Glenn and Rotenberg 1984) and in adults with phonological dyslexia (Moore, Brown, Markee et al., 1995, 1996).

One of the most useful classifications for different subtypes of childhood dyslexia is that proposed by Bakker (1990). This classification – based on reading speed, accuracy and the type of errors made during reading – distinguishes three subtypes of dyslexia, namely perceptual dyslexia (P-Dyslexia), linguistic dyslexia (L-Dyslexia), and mixed dyslexia (M-Dyslexia). Children with P-Dyslexia read relatively slowly but accurately, tend to make time-consuming errors, such as reading words in a fragmented and/or repetitive fashion. Children with L-Dyslexia are relatively fast but inaccurate readers, and their errors mainly consist of omissions and additions of words or parts of
words. Children with M-Dyslexia are slow and inaccurate readers, and make both substantive and time-consuming errors. Around 60% of dyslexic children belong to groups L and P, while the remaining 40% are affected by M-dyslexia. In all three dyslexia subtypes, inattention scores are higher than normal, and as compared to normal children of the same age working memory is reduced (Masutto, Bravar and Fabbro 1994).

The present study was carried out in order to: (a) verify the role played by developmental changes in callosal transfer of tactile information in normal readers and dyslexic children as there are contradictory data in the literature in this regard (Quinn and Geffen, 1986; Pipe, 1991); (b) document the presence of deficits in callosal transfer of finger localization in Italian children with dyslexia; and (c) verify if there are any differences in callosal transfer of finger localization across the three subtypes of dyslexia.

**MATERIALS AND METHODS**

**Subjects**

The control group consisted of 16 children, among whom 8 subjects (2 boys, 6 girls) aged 10-14 years (mean age = 12.2) and 8 subjects (6 boys and 2 girls) aged 6-9 years (mean age = 7.5). None of the control subjects had been diagnosed as having hearing deficits or neurological and/or psychological disturbances, language acquisition disorders or learning disabilities. Younger children, aged 6, had attended one year, at least, of primary school and at the time the present investigation was carried out they were in their second grade. The group of children with dyslexia consisted of 20 subjects, among whom 7 children (all males) aged 10-15 years (mean age = 11.7), and 13 children (12 boys, 1 girl) aged 7-9 years (mean age = 8.2). All children (control and dyslexics) were right-handed as assessed by Briggs and Nebes’ test (1975); their full IQ was higher than 90 (Wechsler, 1993).

**Neuropsychological Assessment**

Developmental dyslexia was assessed according to the *International Classification of Diseases Criteria, 10th Edition* (cf. Guareschi Cazzullo, 1997). All children with dyslexia presented a normal neurological examination, their EEG during wake was regular, they did not have psychiatric disturbances, neither hearing or attention deficit disorders, nor did they show relevant socio-economic difficulties. Their IQ was computed according to the WISC-R scale (Wechsler, 1993) and the average was 107.1 (range 91-154). None of the subjects had language problems as assessed by the language test battery proposed by Ferrari, De Renzi, Faglioni et al. (1981). Reading difficulties were assessed by means of two standardized tests in Italian, namely the *Prove di lettura MT (MT Reading Tests)* by Cornoldi and Colpo (1981) and the *Batteria per la Valutazione della Dislessia e della Disortografia Evolutiva (Battery for the Assessment of Reading and Spelling Disabilities)* by Sartori, Job and Tressoldi (1995). MT tests assess speed and correctness in reading age-related texts (grades 1-8 of primary school). Two tests assessing speed and correctness in reading words and nonwords were selected from Sartori et al.’s battery (1995). A diagnosis of developmental dyslexia was made when children performed at least 2 standard deviations (SD) below the norm in at least one of the reading tests.

Dyslexia subtypes were determined according to the following criteria (as suggested by Bakker, personal communication): P-type if the children’s reading speed was 1 SD below mean age and time consuming errors were higher than, or equal to 60% of total errors in text reading; L-type if their reading speed was 1 SD above mean age and substantial errors were higher than, or equal to 60% of total errors; M-type in all other cases.

Age, IQ and reading scores (accuracy and speed) were compared across all subgroups.
The only significant difference was in reading scores between Dyslexics and Controls (p < 0.005 for accuracy and p < 0.05 for speed respectively).

Test of Callosal Transfer of Tactile Information

Callosal transfer of tactile information was assessed by means of the test developed by Volpe et al. (1979). During the test the child sat on a chair with his/her hands resting comfortably on a table, palms up and fingers spread. The examiner used a pencil to stimulate one finger at a time. Before the beginning of the experiment the child could look at the stimulated finger. Immediately following stimulation the child was required to indicate with the thumb of the same hand (uncrossed localization) or of the contralateral hand (crossed localization) the stimulated finger and related area - distal or proximal. For example, in the crossed localization condition, following stimulation of the distal area of the left index finger, the child responded by touching the distal area of his/her right index finger with his/her right thumb. After the child had understood the task and correctly carried out “within-the-hand” and “between-the-hands” practice trials with his/her eyes open, the very test began. During the test, throughout all conditions, the child remained blindfolded. Each subject carried out 24 trials on each hand (3 trials on each area – distal and proximal – of all fingers, thumb excluded) in both crossed and uncrossed localization conditions (the total number of trials for each subject was 96). All subjects performed the uncrossed localization condition trials first and the crossed localization condition trials afterwards. Choice of the hand with which stimulation was carried out was counterbalanced across all subjects.

RESULTS

Individual results were analyzed using a 4-way ANOVA: group × age × condition × hand (groups = 2, K: Controls and D: Dyslexics; ages = 2, Y: under 10 years, O:
from 10 years of age onwards; conditions = 2: Crossed and Uncrossed; Hand = 2: Right and Left) using gender as covariate. Group, age and condition with the exception of hand turned out to be significant main factors. Control group children made significantly less errors than children with dyslexia \([K = 1.10; D = 2.16; F (1, 32) = 9.74; p < 0.005]\). Younger children made more errors than older children \([Y = 2.17; O = 1.10; F (1, 32), p < 0.005]\). A larger number of errors was made in the crossed localization condition than in the uncrossed localization condition \([U = 0.36; C = 2.91; F (1, 32) = 43.07; p < 0.001]\).

The age-condition interaction was significant \([F (1, 32) = 5.20; p < 0.05]\). Post-hoc Newman-Keuls tests showed that differences between younger and older children in the uncrossed condition were not significant \((YU = 0.45; OU = 0.27; p > 0.05)\), while they were in the crossed condition \((YC = 3.89; OC = 1.93; p < 0.002)\). The group-condition interaction was also significant \([F (1, 32) = 6.88; p < 0.02]\). Post-hoc Newman-Keuls tests showed that, although both children with dyslexia and control children made significantly less errors in the uncrossed localization condition than in the crossed localization condition \((DU = 0.73 \text{ vs. } DC = 3.94; p < 0.001; KU = 0.34 \text{ vs. } KC = 1.87, p < 0.03)\), in the crossed condition children with dyslexia made a significantly larger number of errors than control children \((p < 0.01)\). No significant differences were found in the uncrossed condition \((p > 0.05)\). No other interaction was significant [See Figure 1]. In the control group the sex-condition interaction was not significant. This result confirmed the data presented in the literature supporting the hypothesis of absence of gender differences in this task (Galin et al., 1977; Quinn et al., 1986)

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**Fig. 1 – Mean number of errors as a function of condition (uncrossed and crossed), age (younger vs. older children) and group (control and dyslexics).**
Individual results of children were analyzed by a 3-way ANOVA: subgroups × condition × hand (subgroups = 4: L-Dyslexia, P-Dyslexia, M-Dyslexia and Controls; conditions = 2: Uncrossed and Crossed; hand = 2, Right and Left) using age as covariate. Subgroup and Condition turned out to be significant main factors. Children with L-Dyslexia and M-Dyslexia made a significantly larger number of errors than children with P-Dyslexia and Controls [L-Dyslexia = 2.71; M-Dyslexia = 3.24 P-Dyslexia = 1.10; K = 1.10; F (3,32) = 13.37; p < 0.001]. In the crossed conditions significant differences were found between children with L-Dyslexia and Controls (p < 0.001), children with M-Dyslexia and Controls (p < 0.001), but not between children with P-Dyslexia and Controls (p = 0.99). No significant differences were found between children with M-Dyslexia and L-Dyslexia (p = 0.31). The subgroup-condition interaction was significant [F (3, 32) = 11.06, p < 0.001]. Post-hoc Newman-Keuls test showed that in the crossed condition children with L-Dyslexia and M-Dyslexia made a significantly larger number of errors than children with P-Dyslexia and Controls, whereas no differences were found in the uncrossed condition (Uncrossed: L-Dyslexia = 0.43, M-Dyslexia = 0.24, P-Dyslexia = 0.42, Controls = 0.34; p > 0.05; Crossed: L-Dyslexia = 5.00, M-Dyslexia = 6.25, P-Dyslexia = 1.78, Controls = 1.87). According to these data, in the crossed condition L-types differed significantly from Controls (p < 0.001) and from M-types (p < 0.001) and Controls (p < 0.001); lastly, P-types did not differ from Controls (p > 0.05) [See Figure 2]. Age distribution within subgroups was controlled for using age.

**Condition x Subgroup**

![Mean number of errors as a function of condition (uncrossed and crossed) and subgroup (control, L-dyslexia, P-dyslexia and M-dyslexia).](image)

Fig. 2 – Mean number of errors as a function of condition (uncrossed and crossed) and subgroup (control, L-dyslexia, P-dyslexia and M-dyslexia).
as a covariate. No comparison was made within subgroups because of the small number of subjects in each subgroup. A comparison of L- and M-types with P-types in the younger groups revealed significant differences (p < .02), with P-types making fewer errors than L- and M-types in the crossed condition.

**Discussion**

The present investigation has confirmed findings from previous studies (Galin, Diamond and Herron, 1977; Quinn and Geffen, 1986) whereby both controls and children with dyslexia under 10 years of age made a significantly larger number of errors than children over 10 years of age. This might be due to the fact that in the first 10 years of life callosal functions subserving inter-hemispheric transfer of tactile information come to full maturation (Yakovlev and Lecours, 1967; Salamy, 1978).

The present study has also provided new evidence for a significant deficit of callosal transfer functions in native Italian children with dyslexia. Such deficit had already been highlighted in previous studies on bimanual motor coordination tests (Gladstone et al., 1989; Wennekes and Njokiktjien, 1991), sensory information transfer by means of tachistoscopic techniques (Gross-Glenn and Rothenberg, 1984) and dichotic listening techniques (Beaumont et al., 1981; Fabbro et al., 1986) as well as in studies on callosal transfer of tactile information in children with dyslexia (Fletcher et al., 1982; Gross-Glenn and Rothenberg, 1984) and in phonologically dyslexic adults (Moore et al., 1996).

A possible pathogenetic factor in developmental dyslexia might be a defective callosal transfer determining an insufficient integration and coordination of the activity of both cerebral hemispheres. This hypothesis is in line with several neuroimaging studies that revealed an abnormal size of some portions of the corpus callosum in dyslexics (Duara et al., 1991; Rumsey et al., 1996; Hynd et al., 1995). Such morphological findings in subjects with dyslexia may be related to a deficit in the loss of callosal axons during the perinatal and the first post-gestational weeks (Robichon et al., 1998).

Studies on subjects with agenesia of the corpus callosum (Temple, Jeeves and Villarroya, 1990) and native English adults with developmental dyslexia (Moore et al., 1996) highlighted an association between a deficit in callosal transfer of information and difficulties with phonological processes. Defective callosal transfer of information might therefore play a particularly important role in native Italian subjects if we consider that written Italian tends to be decoded mainly by phonological strategies (see Paulesu, McCrory, Fazio et al., 2000). With regard to the different pattern of results found for P-types as opposed to L- and M-type dyslexics, it should be noticed that P-types seem to rely on sequential, phonological reading strategies more than L-types do (Van Strien, Bouma and Bakker, 1993; Van Strien, 1998). This might well be interpreted as a consequence of defective phonological processes present in L-type but not in P-Dyslexia. Our findings of a defective callosal transfer in children with L-Dyslexia are thus in line with previous data on adults with phonological dyslexia (Moore et al., 1996).
However, the occurrence of deficits in the crossed localization tasks in children with developmental dyslexia might also be related to factors other than a reduction in inter-hemispheric transfer of tactile information; specifically, a reduced ability to perform cognitive tasks requiring spatial representation in mirror-reversed conditions (Quinn and Geffen, 1986; Pipe, 1991). This would be in line with findings showing that dyslexic children perform poorer than controls on some tasks of spatial organization not related to reading (e.g., in copying the Rey-Osterrieth Complex Figure – see Mc Gee, Williams, Moffitt et al., 1989, or more generally in visuoperceptual tasks – see Reid and Hresko, 1985). Moreover, the difference in results between P-types, on the one hand, and L- and M-types, on the other, may probably be explained in these terms. Indeed, significantly lower scores have been reported in tasks of mental rotation (Figure Rotation Test) for L-types vs. P-types (Van Strien, 1994, 1998).

In conclusion, our data lend support to the theories that distinguish among different dyslexia subtypes. Particularly, Bakker’s classification of dyslexia into P, L and M types may be further validated by studies with reading-independent tasks, too – such as interhemispheric transfer of tactile information – highlighting differences between these subtypes.

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