Dyslexia: Verbal impairments in the absence of magnocellular impairments

Martin Kronbichler, Florian Hutzler and Heinz Wimmer[CA]

Department of Psychology, University of Salzburg, Hellbrunnerstr. 34, A-5020 Salzburg, Austria

[CA] Corresponding Author

Received 1 February 2002; accepted 4 February 2002

Sensitivity to dynamic visual and auditory stimuli was assessed in dyslexic children (Grade 7) who at school entrance had suffered from the well-established double-deficit of impaired phonological sensitivity and deficient rapid naming performance. A visual magnocellular deficit was assessed by the coherent motion detection task of the Oxford group. An auditory magnocellular deficit was assessed by the illusory sound movement perception task of Hari and Kiesilä. On both tasks our dyslexic subjects' performance was similar or even better than the performance of normally reading controls. Differences in the inclusion of ADHD cases in dyslexic samples is discussed as a potential explanation of differences in results. *NeuroReport* 13:617–620 © 2002 Lippincott Williams & Wilkins.

Key words: Auditory illusion; Coherent motion; Dyslexia; Magnocellular pathway; Temporal processing

INTRODUCTION

The WHO definition of dyslexia mentions verbal and specifically phonological deficits as causal for the difficulties of dyslexic children in learning to read [1], and thereby reflects the thrust of dyslexia research over the last 25 years. However, there have been recent attempts to reduce the verbal phonological deficits of dyslexic children to impaired sensitivity to rapidly changing stimulus characteristics which affect both audition and vision. Among these attempts, the magnocellular hypothesis is prominent [2]. It traces the dyslexic problems to a particular cell line, called magnocells, which is selectively damaged during brain development. These cells are responsible for the processing of rapidly changing sensory information. In the case of speech, these processes are required for distinguishing phonemes such as /ba/ and /da/. In the case of reading, these processes are required for guidance of eye movements, stable binocular fixation and suppression of image blur during saccades.

Various aspects of the magnocellular deficit explanation of dyslexia are currently debated [3,4]. The strongest counterargument is that the association between magnocellular deficits and dyslexia is spurious. According to Ramus [4], a number of studies failed to find a magnocellular deficit; in studies reporting a deficit, only a minority of the participants showed the deficit, and this minority may show the deficit not because of dyslexia, but because of problems with attention, stemming from a additional attention-deficit/hyperactivity disorder.

Our study examined magnocellular deficit [5] in dyslexic children, recruited from a large longitudinal study on precursors of reading difficulties. All children were native speakers of German. The grapheme–phoneme correspondence is more consistent in German than in English orthography [5]. This probably explains why German children usually find it easier to start reading than do English children and why German dyslexic children do not show marked problems with reading accuracy but rather with reading fluency [6]. The most seriously affected children in our longitudinal study, who suffered from both dysfluent reading and poor orthographic spelling at the end of Grade 3, showed the expected verbal phonological dysfunction at school entrance. They exhibited low performance on phonological sensitivity, phonological memory and rapid automatized naming tasks [7]. For the present study, we again selected children with poor reading fluency and poor spelling from our longitudinal sample. This time, they were already in Grade 7. The question was whether these children suffer from magnocellular deficits which may explain both their early verbal phonological impairments at school entrance and their current reading and spelling deficits.

For the assessment of a magnocellular deficit in vision, the coherent motion sensitivity task of Stein's Oxford group [8] was used. Sensitivity for coherent motion is established as a main function of the magnocellular system and the Oxford group, in four independent studies, has provided evidence for reduced dyslexic performance [8–11]. For a magnocellular deficit in audition, the sound movement illusion of Hari and Kiesilä [12] was used. The illusion is created by trains of binaural clicks which lead to illusory sound movements at short intervals. A sluggish magnocellular system with impaired temporal resolution should lead to higher illusion proneness in dyslexic persons and this was found in a study with Finnish dyslexic adults [12].

MATERIALS AND METHODS

Twenty dyslexic and twenty normally reading boys were recruited from our longitudinal sample of 530 boys, for whom data from the school entrance assessment and the reading and spelling assessment in Grade 3 were available. At the time of the present assessment, all boys were in Grade 7 and were invited to participate, if in Grade 3 they had scored below percentile 15 on both reading fluency and spelling. To be diagnosed as dyslexic, both their present reading and spelling scores had to be below percentile 10. Exclusion criterion was a low nonverbal IQ (< 85) based on three scales (spatial sequences, spatial integration, and spatial concepts) from the Primary Test of Cognitive skills [13]. This test was administered at the end of Grade 1. The control group consisted of boys who both in Grade 3 and presently showed reading and spelling scores > 20th percentile. Testing for the present study was done individually at the Department of Psychology; all testing at school entrance was also done individually in a quiet room in school.

The main measure of the Grade 7 reading assessment was based on an individually administered standardized sentence reading test. Seventy sentences of simple content had to be marked as correct or incorrect and the measure was number of correctly marked sentences within 3 min. The means in Table 1 correspond to the 5th percentile for the dyslexic group and the 60th percentile for the control group. Wrong markings hardly occurred. The spelling measure was based on 29 orthographically complex words (e.g. 'Marktkrise'), and the mean percentages correct in Table 1 again correspond to percentiles 5 and 60, respectively. From Table 1 it is also evident that the reading and spelling deficits of the dyslexic sample were not accompanied by an IQ deficit or by lower age: the dyslexic sample was slightly older than the controls. Table 1 also shows poor speed of our dyslexic sample for reading aloud a short text (227 words), a list of 24 pseudowords (e.g. 'Pfofazi'), and a list of 36 two-digit and three-digit numerals. The pseudowords and numerals were presented in the usual text reading format. Dyslexic error rates on these reading aloud tasks were 17.9% for text, 8.8% for pseudowords and 1.1% for numerals, respectively.

For the assessment of a magnocellular dysfunction in vision, the most recent version of the computerized coherent motion detection task of the Oxford group was used (for specifics on stimulus generation and the staircase procedure for gaining individual thresholds see [8]).

Participants were presented two panels of random dot kinematograms on a computer monitor (Belinea 17 inch, refresh rate 70 Hz) from a distance of 60 cm in a windowless room in the Department of Psychology. The room was illuminated only by a second computer monitor. Each panel contained 300 randomly arranged white dots on a dark background. On each trial (2300 ms duration), the dots of one panel moved randomly, whereas a certain proportion of the dots of the other moved in the same direction. Children were asked to point to the panel with the coherently moving dots. Testing started with 75% of the dots moving coherently and thresholds were determined by a staircase procedure (i.e. one step down after detection, one step up after non-detection). Inserted into the staircase procedure were catch trials (with 75% coherence of one panel), which controlled

Table I. Means (± s.d.) for dyslexic and control boys on reading, magnocellular and verbal measures.

Measure	Dyslexic boys ($n = 20$)	Control boys ($n = 20$)	t (df = 38)
Defining and descriptive measures			
Sentence reading	25.50 ± 4.54	42.90 ± 6.16	− 10.18***
Spelling (% correct)	26.03 ± 14.39	79.48 ± 12.88	− 12.38***
I	101.43 ± 11.15	104.22 ± 13.05	−0.73
Age (months)	164.50 ± 5.86	160.00 ± 3.51	2.95**
Reading rate measures (syllables/min)			
Text	127.95 ± 36.83	240.57 ± 17.61	− 12.34***
Pseudowords	76.80 ± 17.52	124.20 ± 15.58	−9.04***
Numerals	222.61 ± 42.67	269.50 ± 44.21	−3.41**
Magnocellular measures			
Visual coherent motion detection (% dots)			
Ist threshold	13.50 ± 9.94	12.13 ± 6.20	−0.52
2nd threshold	8.29 ± 4.35	9.71 ± 5.55	0.90
Combined threshold	10.89 ± 5.82	10.92 ± 4.96	0.15**
Auditory illusory movement perception			
Illusion judgements (%)	40.45 ± 16.22	50.00 ± 11.52	2.15*
Illusion disappearance (ms)	$150.00^a \pm 120/185^b$	$175.00^a \pm 135/200^b$	1.94^c
Verbal measures			
Pseudoword repetition (% correct)	54.00 ± 21.18	70.67 ± 18.40	−2.66*
Rhyme detection (% correct)	82.33 ± 17.34	94.00 ± 5.25	−2.88**
Onset detection (% correct)	72.50 ± 21.60	82.81 ± 19.01	− 1.60
Pluralization (% correct)	72.69 ± 19.57	87.69 ± 10.11	−3.05**
Rapid naming (syllables/min)	40.16 ± 6.70	46.68 ± 10.64	−2.32*
Rapid articulation (syllables/min)	202.00 ± 40.24	239.50 ± 33.99	−3.18**
Peg moving task (pegs/min)	43.57 ± 4.35	43.31 ± 5.40	0.16

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$ (two-tailed).

^{a}Median, ^{b}scores for 25th and 75th percentile, ^{c}z-value (Mann-Whitney U-test).

for inattention. To familiarize children with the task, three practice trials were presented together with the instruction. The task ended after 10 reversals of the staircase procedure. The threshold was calculated as the geometric mean of the coherence levels, at which the last eight reversals had occurred. Children participated in two runs of the task.

For the assessment of an auditory magnocellular dysfunction, we used the illusory sound movement stimuli developed by Hari and Kiesilä [12]. On each trial, participants are binaurally presented a train of eight clicks through headphones. Each click was of 1 ms duration, the first four with precedence (0.8 ms) of the left ear and the second four with precedence of the right ear. Trains with click intervals of 60, 75, 90, 105, 120, 135, 150, 175, 200, 250 and 300 ms were presented, each click train presented twice resulting in 22 trials altogether. On each trial, children indicated whether the clicks did or did not move. For demonstration of the moving clicks, a train with 45 ms intervals was used, for demonstration of non-moving clicks a train with 500 ms intervals was used. Testing took place in a quiet room and the trains were presented through Serinheiser headphones. As measures we used the percentage of illusory movement responses and the click interval at which the illusion disappeared. The disappearance score was the click interval for which the child failed to detect movement twice and did so (with a single move judgment allowed) at all longer intervals.

The verbal phonological assessment at school entrance consisted of the following tasks. A pseudoword repetition task (15 items) required immediate repetition of single pseudowords which always consisted of three confusable syllables (e.g. 'liruli'). For the rhyme detection task (15 items) children were asked "What rhymes with cat: fit or fat?" with the two alternatives differing by one phoneme only. In the onset detection task (16 items) we presented three words and subsequently specified the onset, (e.g., mother, needle, berry: which one begins with 'm'?). In the pluralization task (15 items) children had to respond with the plural to a given singular (e.g. experimenter: one mouse, child: two mice). In a rapid naming task (two trials with different pictures) children were asked to name quickly a sequence of 20 pictured objects (five pictures of well known objects, each repeated four times). For rapid articulation (two trials with different word triples) they had to repeat as quickly as possible for 10 s a familiar word triple (German equivalents of dog, cat, mouse and knife, fork, spoon). The peg moving task of Annett [14] required children to move 10 pegs from one line of holes to the opposite line with two trials for both the right and the left hand. This task served as a control for a general speed impairment.

RESULTS

The lower section of Table 1 shows how the dyslexic group performed on the magnocellular tasks and on the verbal tasks in comparison to the control group. The *t*-values are poled in such a way that poorer performance of the dyslexic group is indicated by a negative *t*-value. The group difference for the auditory illusion score (based on not equally paced click intervals) was assessed by Mann-Whitney U-test and a z-value is given.

Table 1 shows a simple pattern. On the magnocellular tasks the dyslexic group tended to perform better than the control group. The only exception was the first threshold of the motion detection task. In contrast, on the verbal tasks, the dyslexic group performed markedly poorer than the control group: only for onset detection was the deficit not reliable. The two-tailed p-values in Table 1 are conservative because theoretical expectation and prior findings speak for a dyslexic deficit. Of importance is that the rapid naming and rapid articulation deficits of the dyslexic group were not accompanied by a speed deficit on the non-verbal peg moving task.

Inspection of the individual scores on the magnocellular tasks showed that one dyslexic boy performed very poorly on the first run of the motion detection task (threshold: 50% coherence), but was above average (7% coherence) on the second. Inspection of responses to the illusory sound movement items showed that one dyslexic boy even from the shortest click interval (60 ms) onwards consistently denied to hear any sound movement. Exclusion of this boy did not eliminate the tendency towards better performance of the dyslexic group.

Because the dyslexic children were on average about 4 months older than the control group, we examined the correlations between age and magnocellular measures (coherent motion detection threshold, auditory illusion judgment percentage, illusion disappearance interval). All coefficients were smaller than Spearman $r = 0.14$, $p > 0.42$.

DISCUSSION

The main findings were that our dyslexic participants despite severe reading fluency and spelling deficits did not show impaired sensitivity to dynamic visual and auditory stimuli. Their performance on these tasks was equal to or tended to be better than the performance of the age-level control group. This unimpaired performance on the magnocellular task stands in marked contrast to the deficits of the dyslexic group on the verbal phonological and rapid naming tasks at school entrance.

The present failure to find poor dyslexic performance on the coherent motion detection task is discrete from the findings of the Oxford group with English dyslexic participants: one study with dyslexic children, three with dyslexic adults [8–11]. Procedural differences can hardly account for the different results, because the procedure of the Oxford group was used, and the mean detection threshold (i.e. 11%) of our 13–14 year olds fits well into the developmental pattern established by the Oxford studies (i.e. 18% for 10-year-olds [15], 8% for adults [8]).

Similar to the absence of a visual magnocellular deficit among the present dyslexic subjects, there was no evidence for an auditory magnocellular deficit. Actually, there was a tendency to the opposite. A procedural difference to the original study [12] was that instead of spatially locating each of the eight clicks of each trial on a response sheet, our participants simply judged the presence or absence of click movement. This response simplification should not affect perception and actually the illusion began to disappear at about the same click intervals (from 90 ms upwards) as in the Finnish study. However, whereas the Finnish dyslexic adults were prone to the illusion at click intervals of > 250 ms none of the present dyslexic children reported a movement illusion at such long click intervals. The present absence of an auditory magnocellular deficit suggests that the phonological deficits of our dyslexic children cannot be explained by deficient auditory input [16].

Because we used the same tasks for the assessment of a magnocellular deficit as the Oxford group [8–11] and Hari and Kiesilä [12], the failure to find a dyslexic deficit may have to do with differences in subject selection. One may reason that the present dyslexic sample suffered from less serious reading difficulties than the dyslexic samples of the mentioned studies. This is difficult to rule out. However, the reading and spelling difficulties of our dyslexic cases were individually ascertained two times (both in Grade 3 and Grade 7) and were serious both in absolute terms (e.g. their reading rate was only about half the rate of the average readers) and in relation to norm (< 10th percentile). Furthermore, our sample showed the phonological and rapid naming deficits, which are typically found for dyslexic samples in Anglo-American studies [17]. An interesting possibility is that our diagnosis of reading difficulties (i.e. slow reading time) may be less prone to include dyslexic children with additional attention-deficit/hyperactivity problems than the diagnosis of reading difficulties used for English-speaking children and adults. The English dyslexia diagnosis is typically based on graded word reading test, that is, on high number of errors. These reading errors in part may result from fast impulsive responses. The German dyslexia diagnosis by slow reading time may exclude such fast impulsive responders. This interpretation is in line with the critique by Ramus [4] that the association between magnocellular deficits and dyslexia may be spurious and result from the inclusion of ADHD cases in the dyslexic samples. Of course, direct evidence for the validity of the interpretation is needed by testing dyslexic children with and without a comorbid ADHD problem. In this context, it is important that the present negative findings on visual magnocellular deficits of dyslexic persons are not singular. Specifically, similar negative results were reported in two other studies with dyslexic children in more regular orthographies [18,19].

CONCLUSION

The present study showed that the slow visual word processing of German dyslexic children in reading and their poor spelling is not accompanied by impaired coherent motion detection. Similarly, these dyslexic children showed no proneness to auditory movement illusions which would be taken as an indication of a sluggish magnocellular auditory pathway. However, before the onset of reading acquisition the dyslexic participants of the present study had shown the verbal-phonological and rapid naming deficits which are taken as evidence for the phonological deficit explanation of dyslexia [20,21] and for the recent extension of this explanation by Wolf and Bowers [17].

REFERENCES

1. Dilling H, Mombour W and Schmidt MH. *International Classification of Mental Diseases*. ICD-10 (German edition). Bern: Huber; 1991.
2. Stein JF and Talcott JB. *Dyslexia* **5**, 59–78 (1999).
3. Skottun BC. *Vision Res* **40**, 111–127 (2000).
4. Ramus F. *Nature* **412**, 393–395 (2001).
5. Wimmer H and Goswami U. *Cognition* **51**, 91–103 (1994).
6. Landerl K, Wimmer H and Frith U. *Cognition* **63**, 315–334 (1997).
7. Wimmer H, Mayringer H and Landerl K. *J Educ Psy* **92**, 668–680 (2000).
8. Hansen PC, Stein JF, Orde SR *et al. Neuroreport* **12**, 1527–1530 (2001).
9. Cornelissen P, Richardson A, Mason A *et al. Vision Res* **35**, 1483–1494 (1995).
10. Talcott JB, Hansen PC, Willis-Owen C *et al. Neuro-Opthalmology* **20**, 187–201 (1998).
11. Talcott JB, Hansen PC, Assoku EL *et al. Neuropsychologia* **38**, 935–943 (2000).
12. Hari R and Kiesilä P. *Neurosci Lett* **205**, 138–140 (1996).
13. Huttenlocher J and Cohen-Levine S. *Primary Test of Cognitive Skills*. Monterey, CA: Macmillan/McGraw-Hill, 1990.
14. Annett M. *Left, Right, Hand and Brain. The Right Shift Theory*. Hillsdale: Erlbaum; 1985.
15. Talcott JB, Witton C, MacLean MF *et al. Proc Natl Acad Sci USA* **97**, 2952–2957 (2000).
16. Farmer ME and Klein RM. *Psychon B Rev* **2**, 460–493 (1995).
17. Wolf M and Bowers P. *J Educ Psychol* **91**, 415–438 (1999).
18. Walther-Müller P. *Perception* **24**, 919–936 (1995).
19. Spinelli D, Angelelli P, De Luca M *et al. Neuroreport* **8**, 1807–1812 (1997).
20. Shaywitz SE. *Sci Am* **275**, 98–104 (1996).
21. Snowling MJ. *Dyslexia*. Oxford: Blackwell; 2000.

Acknowledgements: We are grateful to John Stein and Joel Talcott for making available the software for the assessment of coherent motion detection. Thanks to Riitta Hari for providing the stimuli for the auditory movement illusion task. The research reported here was supported by the Austrian Science Foundation (Grant No. P12481 and P914494).