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On the automaticity/cerebellar deficit hypothesis of dyslexia: balancing and continuous rapid naming in dyslexic and ADHD children

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Abstract

The present study examined the relationship of reading disability (RD) and attention deficit hyperactivity disorder (ADHD) to balancing problems. In the cerebellar deficit hypothesis of dyslexia of Nicolson et al. [Trends Neurosci. 24 (2001) 508], balancing problems are taken as sign of a cerebellar deficit and were found to be associated with dyslexia. Four groups of 10 children each, representing all combinations of RD (absent versus present) and ADHD (absent versus present), were included. However, poor balancing (assessed both singly and together with a secondary task) was not found to be associated with RD, but with ADHD. In contrast, poor performance on continuous rapid naming tasks (digit and color naming) was found to be associated with RD and not with ADHD.

Keywords: Dyslexia; ADHD; Cerebellum; Balancing; Rapid naming

1. Introduction

In a series of publications, Nicolson and Fawcett, and their collaborators in Sheffield elaborated and substantiated the hypothesis that difficulties in learning to read reflect a general impairment in the ability to acquire skills, that is, to automatize repeatedly performed behavioral or cognitive sequences (e.g. Nicolson & Fawcett, 1990, 1995). The original finding was a massive difficulty with balancing of dyslexic children—particularly when performing a secondary task (Nicolson & Fawcett, 1990, 1995). The focus on general skill automatization distinguishes this hypothesis from more specific rival explanations of dyslexia. The dominant phonological deficit explanation assumes a specific difficulty with phonemic awareness which is linked to a specific deficit in speech perception (e.g. Snowling, 2000). The magnocellular deficit hypothesis in its dominant version assumes degraded visual input due to poor binocular fixation as the cause of the reading difficulties (e.g. Stein, 2001).

Recently, the Sheffield group linked the hypothesized automatization deficit to a dysfunction of the cerebellum (Nicolson, Fawcett, & Dean, 2001). The original balancing deficit was interpreted as one of several "cerebellar signs" such as hypotonia of the upper limbs (e.g. hand wobble after arm shake) or poor maintenance of movement patterns (e.g. speed of toe tapping) (Fawcett & Nicolson, 1999; Fawcett, Nicolson, & Dean, 1996). Poor time estimation was found as a non-motor cognitive symptom of a cerebellar dysfunction (Nicolson, Fawcett, & Dean, 1995). Recently, neuroanatomical and neuroimaging findings were supplied in support of cerebellar anomalies in dyslexic persons (Finch, Nicolson, & Fawcett, 2002; Jenkins et al., 1994; Nicolson et al., 1999; Rae et al., 1998, 2002). The automaticity/cerebellar dysfunction hypothesis and the evidence in support of it recently elicited comments (Beaton, 2002; Bishop, 2002) and discussion (Ivry & Justus, 2001; Nicolson et al., 2001; Zeffiro & Eden, 2001).

A main implication of the automaticity/cerebellar deficit hypothesis is the presence of motor deficits in dyslexic children. This implication is contentious. Some time ago, Denckla, Rudel, Chapman, and Krieger (1985) argued that motor impairments were mainly found in dyslexic children who also suffered from attentional hyperactivity problems. Ramus, Pidgeon, and Frith (2002) studied the presence of motor deficits in a sample of English dyslexic children and found deficits in postural stability, bead threading and in the finger to thumb task, but about half of the dyslexic group did not exhibit motor problems and part of the motor deficit of the dyslexic group was due to that half of the dyslexic sample which had received an additional diagnosis (attention deficit hyperactivity disorder, ADHD or developmental coordination disorder). A study from our

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lab with German dyslexic children found that balancing problems disappeared when dyslexic children with additional ADHD symptoms were excluded from the sample (Wimmer, Mayringer, & Raberger, 1999). Two studies with Dutch dyslexic children gave inconsistent results. Yap and van der Leij (1994) did find balancing difficulties, which were mild compared to the Sheffield results, but Van Daal and van der Leij (1999) did not find any balancing deficits in another dyslexic sample. From this pattern of findings one may infer that the marked motor and balancing deficits of dyslexic children studied by the Sheffield group may have resulted from the inclusion of a higher number of co-morbid children (ADHD or developmental coordination disorder) in the dyslexic sample. This apparently was not the case. In a review of their studies, Nicolson et al. (2001) state that their dyslexic participants were screened for comorbid disorders, and Fawcett et al. (1996) report that none of their dyslexic participants fulfilled the criteria for an ADHD diagnosis.

Given these discrepant findings and the concern about a confound between dyslexia and ADHD, the present study in a 2×2 design crossed reading disability (absent versus present) and ADHD (absent versus present) and examined balancing deficits. As mentioned, balancing deficits of dyslexic children gave rise to the automatization deficit hypothesis and are considered a sign of cerebellar dysfunction. Our main alternative task was continuous rapid naming of digits introduced by Denckla and Rudel (1976). A deficit on such tasks is taken by the double-deficit hypothesis of dyslexia (Wolf & Bowers, 1999) as an indication of a second main deficit of dyslexic children; a deficit which is largely independent from the well-established phonological awareness deficit. Indeed, studies with German dyslexic children (Wimmer, 1993; Wimmer & Mayringer, 2002; Wimmer, Mayringer, & Landerl, 1998) and with Dutch dyslexic children (Van Daal & van der Leij, 1999; Van den Bos, Zijlstra, & Spelberg, 2002) consistently found rapid naming deficits as a main cognitive associate of the reading difficulties. In contrast, deficits in phoneme awareness deficits were absent or relatively small. This pattern of deficits is not astonishing as dyslexic children in more regular orthographies than English suffer primarily from dysfluent slow effortful reading, whereas reading errors even for pseudowords are relatively infrequent (e.g. Landerl, Wimmer, & Frith 1997a; Wimmer, 1993). We note that the slow, effortful, but largely correct reading of dyslexic children in regular orthographies and the associated deficit on rapid "automatized" naming tests fits well within the general perspective of the automatization deficit hypothesis of the Sheffield group.

2. Materials and methods

2.1. Participants

Because there are no schools for dyslexic children in Austria, selection of participants had to be done within the normal school system. After parental consent, teachers of grade 4 classrooms were asked to nominate children with severe reading and/or severe attentional hyperactivity problems. Teacher nominations were checked by individually administering the text reading subtest of a standardized reading test battery (Landerl, Wimmer, & Moser, 1997b) and by having teachers rate each nominated child on Conners' (1973) abbreviated parent–teacher questionnaire. For keeping a child in an initial pool of qualifying children, the reading rate (syllables per minute) had to be below percentile 20 and/or the ADHD rating had to be at or above percentile 80 on the Conners' questionnaire. This questionnaire consists of 10 items such as "*x* is restless and overactive" or "*x* is constantly fidgeting" with responses ranging from 0 (not at all) to 3 (quite strongly) and a maximum score of 30. Children with an ADHD score corresponding to percentile of 80 and higher were kept in the sample. These percentiles were based on the parental norms of Rowe and Rowe (1997) for 9–11-year-old children in the USA. Furthermore, Raven's colored progressive matrices were individually administered for an assessment of nonverbal intelligence and all children with an IQ of 85 or lower were excluded.

Comorbid children (RD + ADHD) were difficult to find. Teachers nominated children for this group less frequently than for the RD only or for the ADHD only group, but the main problem was that children nominated for the comorbid group (mostly boys) often did not fulfil the ADHD criterion of percentile 80 or higher on the Conners' questionnaire. One reason could be that the US norms for the Conners' questionnaire were not appropriate for our sample. Possibly, American parents (the norm sample for the Conners' questionnaire) more readily attribute ADHD symptoms than Austrian teachers. Altogether, teachers of 40 classrooms had to be contacted to find 10 children (8 boys, 2 girls) who fulfilled the ADHD criterion in addition to poor reading rate. In fact, the reading rates of these children on the text reading subtest were all very low and corresponded to percentiles below 5. In contrast, their ADHD problem—based on the American percentile norms—appeared less severe with three children receiving ratings only slightly above percentile 80.

The 10 participants for the RD only group and for the ADHD only group were obtained by selecting from the initial pool of qualifying children a close match for each participant of the RD + ADHD group. The participants of the RD only group were matched with those of the RD+ADHD group with respect to reading rate, nonverbal IQ, age and sex. However, their ADHD ratings had to be as low as possible. The same selection strategy was applied to the ADHD only children, who were matched to the RD + ADHD children as closely as possible on ADHD percentile, nonverbal IQ, age and sex, but had to exhibit reading rates above percentile 20. The 10 children of the non-impaired group were matched to the RD + ADHD children on nonverbal IQ and age, but had to exhibit reading rates above percentile 20 and ADHD scores below percentile 80.

2.2. Balancing assessment

The balancing tasks were modeled after Nicolson and Fawcett (Nicolson & Fawcett, 1990, 1995). Children were instructed to stand as still as possible on a beam (9 cm high, 9 cm wide, 60 cm long) placed on a rubber mat, first with both feet and then in counterbalanced order with the right or the left foot, respectively. In contrast to the Sheffield studies, they were instructed to keep their arms straight down as in pretrials children had complained about having to stand with arms stretched out. Each balancing task was first performed for 30 s without a secondary task (single-task balancing) and then for 30 s together with a semantic judgement task (dual-task balancing). When a child stepped off the beam, extra time was given so that each child remained on the beam for 30 s for each task. The semantic judgement task presented 14 words on a tape recorder (for each of the 30 s trials) and the child had to respond with "yes" to animals and with "no" otherwise. Scoring of balancing performance followed Nicolson and Fawcett (1995) and was done on the basis of video recordings. The videos were taken frontally and, to enhance visibility, children performed in front of a white poster. Movements of each arm, of the free leg (in the one-foot task) and of the torso were measured separately. For each measurement, a transparency with an array of angular lines was placed on the video screen and adjusted to the optimal vertical direction of the to be measured body part. Then the video was played forward until a movement reached its maximum deviation from the vertical. Movements with deviation below 10° were not scored, deviations between 10 and 20° received half a wobbling point, deviations between 40 and 60° one point and those over 60° two points. Tipping down with the second foot (in the one-foot tasks) resulted in one point, stepping off the beam resulted in two wobbling points. The separate scores for each arm, the free leg in the one-leg tasks and for torso movements were added into a final score for each trial, which was found to reflect mainly arm movements.

2.3. Continuous rapid naming

Following Denckla and Rudel (1976) children were presented with a digit and a color naming task. In case of the digits, the task was to name as quickly as possible 50 digits (5 different digits each repeated 10 times) presented on a single page with 10 lines and 5 digits per line. The digits were 4, 7, 6, 9, 2. The sequence varied from line to line. A practice task preceded the test trial and specified the rapid naming instruction. The color naming task was analogous with five different color dots (i.e. black, green, red, blue and yellow) instead of digits. The German color names are all mono-syllabic. The time for naming the 50 items on the test page constituted the critical measurement. Errors hardly occurred.

3. Results

The upper section of Table 1 shows the effect of the selection and matching criteria on descriptive characteristics of the four groups. Reading time for the text was converted into syllables per minute for an easier impression of dysfluent reading. The mean syllable per minute scores of both the RD only and the RD + ADHD group indicate severely impaired reading fluency. In absolute terms, these rates amount to only 1.5 syllables per second and are only about half of the rate shown by the non-impaired and the ADHD only group. These rates correspond to a delay of 2 years in reading development. Of importance is the specificity of the reading fluency problem of the RD only children as their nonverbal IQ scores were all in the normal range (lowest 96), and for the majority of them, the ADHD score was below percentile 60. Additional findings from the individually administered reading battery showed that 7 of the 10 RD only children showed reading rates of below percentile 5 for pseudowords and 6 did so for short high-frequency words. Also of importance is the specificity of the ADHD symptoms

Table 1
Selection criteria and performance on one-foot-balancing and rapid naming

Measures	RD only ($N = 10$, 8 boys)		RD + ADHD ($N = 10$, 8 boys)		ADHD only ($N = 10$, 9 boys)		Non-impaired ($N = 10$, 8 boys)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Reading fluency (syllables per minute)	103.30	7.25	94.86	14.83	200.42	30.99	221.43	25.83
ADHD score (Conners')	4.30	2.50	16.90	5.13	19.30	2.50	2.00	1.94
Age (months)	123.80	2.57	124.60	7.79	124.80	4.87	123.30	3.65
Raven's CPM IQ	110.20	11.89	107.90	12.39	112.70	10.97	109.30	3.80
Balance (wobbling score)								
Single-task	1.10	1.35	10.55	24.41	11.25	14.37	1.43	1.76
Dual-task	3.33	2.95	8.23	15.97	10.05	12.34	2.50	3.18
Rapid naming (syllables per minute)								
Colors	54.34	12.77	50.60	14.49	63.58	17.93	64.64	15.54
Digits	124.27	20.71	124.73	14.15	151.29	31.47	161.98	36.03

RD, reading disability; ADHD, attention deficit hyperactivity disorder.

of the ADHD only group. As evident from Table 1, the mean reading fluency of these children corresponded to that of the non-impaired group and their mean nonverbal IQ was above average. With respect to age, nonverbal IQ, the groups were similar. In each, the large majority was male.

The lower section of Table 1 shows the wobbling scores for balancing on one foot, separately for single- and dual-task balancing. The wobbling scores for left and right foot (30 s each) were averaged. Results for balancing on two feet are not given as all means were very low (all below 1.5 wobbling points). As there was little difference between single- and dual-task balancing, the scores for the two tasks were combined. This combined wobbling score was used as dependent measure in an ANOVA with factors RD (absent versus present) and ADHD (absent versus present). The only reliable effect was the main effect of ADHD, $F(1, 36) = 4.30$, $P < 0.05$, with wobbling means of 20.0 and 4.27 for ADHD and non-ADHD children, respectively. Neither the main effect of RD nor the interaction between the two factors was reliable, both $F_s < 0.5$.

Table 1 also shows the performance of the four groups on the continuous rapid naming tasks. The naming time was converted into syllable per minute scores to allow comparison with reading fluency. As evident from Table 1, the RD only and the RD + ADHD group showed similar and lower means on both tasks than the two groups without RD (ADHD only and non-impaired). A MANOVA with digit and color naming as dependent measures and RD (absent versus present) and ADHD (absent versus present) as group factors gave a reliable main effect for RD, $F(2, 35) = 4.84$, $P = 0.014$. Neither the main effect of ADHD nor the interaction between ADHD and RD was reliable, $F_s < 1.0$.

4. Discussion

The results of this investigation can be easily summarized: poor balancing was found among ADHD only and RD + ADHD children, but not among RD only children. The balancing of the RD only group did not differ from that of the non-impaired group. In contrast, poor rapid naming was found among RD only and RD + ADHD children, but not for the ADHD only group. The rapid naming performance of ADHD only group did not differ from that of the non-impaired group. Therefore, poor balancing was associated with ADHD and not with reading disability, whereas poor rapid naming was associated with reading disability and not with ADHD.

The absence of balancing difficulties among the RD only group is in correspondence with our previous failure to find balancing problems among poorly reading German-speaking children when children with ADHD symptoms were excluded (Wimmer et al., 1998, 1999). It also corresponds to the failure of Van Daal and van der Leij (1999) to find balancing difficulties in Dutch dyslexic readers who similar to our German children suffer primarily from poor reading fluency and less from errors. The absence of balancing difficulties in the RD only and the presence of such difficulties in the RD + ADHD group corresponds to findings of aggravated motor skill problems in comorbid dyslexic children as compared to pure dyslexic children (Denckla et al., 1985; Ramus et al., 2002). The new finding of the present study is that balancing difficulties were not limited to comorbid children, but were also found among children who suffered from ADHD only. Thus, we did find children who exhibited balancing difficulties—presumably indicative of an automatization cerebellar deficit—but nevertheless were fluent readers. We note that the difficulty of ADHD children with suppression of extra movements on the balance beam and with concentration on external reference for calibration of compensatory movements is not astonishing. In this perspective, balancing poses executive control problems which are known to be difficult for ADHD children (Pennington, Groisser, & Welsh, 1993). It still remains open why in the Sheffield studies massive balancing difficulties were found despite screening for ADHD and why in the present and in the other mentioned studies no such difficulties were found. One may speculate that the selection of German and Dutch dyslexic children based on slow dysfluent reading may bias selection towards exclusion of fast impulsive responders, that is, of ADHD children with an executive control problem. In contrast, the selection of English dyslexic children based on erroneous reading without measurement of reading time may bias selection towards inclusion of ADHD cases.

The second finding of the present study was that poor performance on the continuous rapid naming tasks was associated with dysfluent reading but not with ADHD. The poor rapid naming performance of the present dyslexic children corresponds to earlier findings from German and Dutch dyslexic children (Van Daal & van der Leij, 1999; Van den Bos et al., 2002; Wimmer, 1993; Wimmer & Mayringer, 2002; Wimmer et al., 1998). Interestingly, poor rapid naming of dyslexic children was found not to be accompanied by slow articulation (Van Daal & van der Leij, 1999) or slow visual processing (Wimmer & Mayringer, 2001). Therefore, it seems that specifically the speed of access from visual to verbal codes is impaired in dyslexic children.

The slow, effortful, but largely correct reading of dyslexic children in regular orthographies and the association of poor rapid naming with dysfluent reading is in general correspondence with the automatization deficit hypothesis of Nicolson et al. (2001). Obviously, both the dysfluent reading and the poor rapid naming, particularly the poor naming speed for frequently read digits, can be interpreted as a failure to automate frequently performed cognitive processes. However, the present failure and previous difficulties in finding balance deficits of dyslexic children in regular orthographies speaks for a more constrained version of the automatization deficit hypothesis. Given the mentioned pattern of findings we suggest that only the automatization of processes connecting vision with language may pose a problem for dyslexic children. Possibly, a specific cerebellar dysfunction affects only the automatization of such visual–verbal processes. Other cerebellar functions which are responsible for the automatization of basic sensory-motor skills such as balancing may not be affected in dyslexic children. Such a revision of the automaticity/cerebellar deficit hypothesis would fit the present findings, but also the observation that the problems of many dyslexic boys disappear when in recess they move from the classroom to the soccer-field.

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