Do Children With Focal Cerebellar Lesions Show Deficits in Shifting Attention?


Departments of Neurosurgery, Neurology, Pediatric Hematology and Oncology, Orthopedic Surgery, and Neuroradiology, University of Duisburg-Essen, 45122 Essen, Germany

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INTRODUCTION

In the last two decades, an increasing number of studies in cerebellar patients and in healthy subjects using functional brain imaging techniques claimed evidence for an involvement of the cerebellum in cognitive function (Bower and Parsons 2003; Cabeza and Nyberg 2000; Schmahmann 1997; Thach 1998). Attention is one of the major cognitive functions of human brain, which allows subjects to declare information as relevant and suppress other signals as irrelevant. Different parts of the brain have been shown to be involved in attention, including prefrontal cortex, parietal cortex, thalamus, basal ganglia, and midbrain (Laberge 2000; Thier et al. 2002).

The work of Courchesne and coworkers suggests an additional role of the cerebellum in attention (Courchesne and Allen 1997). In a classic paper, Akshoomoff and Courchesne (1992) investigated five children with chronic surgical cerebellar lesions and one young adult with an idiopathic cerebellar degenerative disorder. Subjects had to perform two tasks. In a focus attention task, subjects had to respond to a single rare stimulus, a red square or a high-pitched tone. In the shift attention task, subjects had to switch between the two rare stimuli, i.e., they had to respond in turn to the red square and the high-pitched tone. Subjects with cerebellar lesions were unimpaired in their ability to focus on the single rare stimulus but showed a significant impairment in the ability to shift attention between stimuli of two modalities particularly within short interstimulus intervals (<2.5 s). Similar findings were later reported in the same five children with surgical lesions included in the initial study using a slightly different paradigm (Akshoomoff and Courchesne 1994). Here, subjects had to shift attention between sensory stimuli of the same visual modality (color and form). Findings in children with cerebellar damage are further supported by functional MRI (fMRI) studies in healthy human subjects (Allen et al. 1997; Le et al. 1998).

Courchesne and coworkers observed similar deficits of shifting attention in children with autism (Courchesne 1997; Courchesne et al. 1994). On the basis of MRI and pathological observations, the authors proposed that disorders in rapidly shifting attention in autism were due to malfunction of the neocerebellum (both hemispheres and vermlobules VI and VII).

Courchesne’s view that the cerebellum plays a role in shifting attention has recently been challenged. Helmut et al. (1997) failed to observe deficits in adult patients with cerebellar disorders in a series of attention shifting tasks. The authors suggested that differences in findings were due to more demanding motor requirements in Courchesne’s studies. In a subsequent experiment, Ivry and coworkers used Courchesne’s original shifting-attention paradigm (Ravizza and Ivry 2001). Deficits in shifting attention showed significant improvement when the motor demands of the task were reduced, i.e., when subjects had to overtly respond to targets in one modality only. Findings of a recent fMRI study of the same group supported Ivry’s hypothesis that the role of the cerebellum in shifting attention tasks is involvement in response reassignment rather than attention (Bischoff-Grethe et al. 2002).
The aim of the present study was to replicate Courchesne’s initial findings in a larger group of children with acute focal cerebellar lesions. A paradigm was used closely related to the initial study of Akshoomoff and Courchesne (1992). Stimuli were presented within two sensory modalities (i.e., auditory and visual stimuli). In the visual domain, different forms (ellipse and circle) were used because possible involvement of the cerebellum in color discrimination has been suggested (Claeys et al. 2003; Schöls et al. 1996). Because previous deficits were most marked in short interstimulus intervals (2.5 s), reaction to stimuli with short time intervals was analyzed in more detail, i.e., results were analyzed separately for time intervals of <1 and 1–2 s. Detailed MRI analysis was performed to take into account whether parts of the neocerebellum were affected or not.

METHODS

Subjects

Ten children with cerebellar lesions and 10 children without neurological disorders participated. The average age was 13.1 ± 2.7 (SD) yr (range: 8–16 yr) in the cerebellar group and 13.8 ± 2.8 yr (range: 10–18 yr) in the control group. In each group, seven of the children were female and three male; eight children were right-handed and two were left-handed. There were no major differences in the level of education between the control and cerebellar groups.

Five children presented with astrocytoma, two with medulloblastoma, one with bleeding out of an av-angioma, and one with acoustic neurinoma. One child (cb 5) suffered from cerebellar hemorrhage of unknown cause. Two children (cb 3, cb 10) had received radiation and chemotherapy because of medulloblastoma. None of the children were taking centrally acting medication except corticosteroids. One of the children (cb 10) had received external drainage for preoperative obstructive hydrocephalus. None of the children needed permanent shunting. The descriptive data of the patients and controls are summarized in Table 1.

Cerebellar children were examined at the earliest time after surgery when successful testing was possible. In nine patients, the average time after the operation was 71.1 ± 83.9 (SD) days (median: 28, range: 6–225 days). In cb 5, testing was performed 3 weeks after first symptoms of cerebellar hemorrhage. At the time of the testing, five of the cerebellar children were hospitalized.

The neurological examination included the ataxia rating scale from Trouillas et al. (1997). Six cerebellar children presented with mild signs (total ataxia score <10 of 100), two with moderate signs (total ataxia score: 10–20) and two children with marked signs of cerebellar ataxia (total ataxia score: >20). Four children presented with cranial nerve involvement. One child (cb 5) showed mild signs of pyramidal involvement (reflex hypermetria). There was no visual and hearing impairment based on clinical examination except in one child (cb 2) who was deaf on the right ear due to acoustic neurinoma.

To control unspecified effects of surgery and hospitalization in those cerebellar children who have been tested while they were hospitalized, in the control group six children were included who had been treated in the local orthopedic department for surgery. Testing was performed on average 7.3 ± 0.81 days after the orthopedic operation (median: 7.5, range: 6–8 days). All six children were hospitalized at the time of the testing. The remaining four children were healthy children. Neurological examination was normal in all control children. The controls did not receive any medication modifying nervous system functions.

The local ethical committee of the University of Essen approved the study. All children and their parents gave informed written consent.

TABLE 1. Data on patients with cerebellar lesions and control subjects

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age/Gender</th>
<th>School</th>
<th>Diagnosis</th>
<th>Symptom Onset Preoperation</th>
<th>Time Since Operation*</th>
<th>Ataxia score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cerebellar group</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cb 1</td>
<td>10/f</td>
<td>Primary</td>
<td>Pilocytic astrocytoma</td>
<td>4 m</td>
<td>28 d/1 d</td>
<td>PG 1 1 1 1 1 8</td>
</tr>
<tr>
<td>Cb 2</td>
<td>14/f</td>
<td>Comprehensive</td>
<td>Acoustic neurinoma (r)</td>
<td>6 m</td>
<td>14 d/2 d</td>
<td>PG 1 1 1 4 5 27</td>
</tr>
<tr>
<td>Cb 3</td>
<td>17/f</td>
<td>Comprehensive</td>
<td>Medulloblastoma</td>
<td>1 m</td>
<td>114 d/128 d</td>
<td>PG 1 1 1 1 5 16</td>
</tr>
<tr>
<td>Cb 4</td>
<td>15/m</td>
<td>Comprehensive</td>
<td>Astrocitoma WHO II</td>
<td>6 m</td>
<td>10 d/2 d</td>
<td>PG 3 3 3 2 6 3</td>
</tr>
<tr>
<td>Cb 5</td>
<td>12/f</td>
<td>Grammar</td>
<td>Intracerebellar Hemorrhage (r)</td>
<td>3 w/3 w***</td>
<td>4.5 5 2 0 1 11.5</td>
<td>OC 1 1 1 1 1 1</td>
</tr>
<tr>
<td>Cb 6</td>
<td>13/f</td>
<td>Comprehensive</td>
<td>Xanthoastrocytoma</td>
<td>9 m</td>
<td>50 d/50 d</td>
<td>OC 1 1 1 1 1 1</td>
</tr>
<tr>
<td>Cb 7</td>
<td>8/f</td>
<td>Primary</td>
<td>Pilocytic astrocytoma (r)</td>
<td>None**</td>
<td>7 d/1 d</td>
<td>SP 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Cb 8</td>
<td>14/m</td>
<td>Comprehensive</td>
<td>Astrocytoma WHO II</td>
<td>12 m</td>
<td>6 d/8 d</td>
<td>SP 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Cb 9</td>
<td>12/f</td>
<td>Grammar</td>
<td>Av-angioma</td>
<td>2 w</td>
<td>275 d/168 d</td>
<td>OC 1 1 1 1 1 1</td>
</tr>
<tr>
<td>Cb 10</td>
<td>16/m</td>
<td>Disabled</td>
<td>Medulloblastoma</td>
<td>4 m</td>
<td>186 d/128 d</td>
<td>OC 1 1 1 1 1 1</td>
</tr>
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<td>Control group</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cn 1</td>
<td>11/f</td>
<td>Grammar</td>
<td>Leg shortening</td>
<td>8 d</td>
<td>0 0 0 0 0 0</td>
<td></td>
</tr>
<tr>
<td>Cn 2</td>
<td>16/f</td>
<td>Grammar</td>
<td>Leg shortening</td>
<td>8 d</td>
<td>0 0 0 0 0 0</td>
<td></td>
</tr>
<tr>
<td>Cn 3</td>
<td>15/f</td>
<td>Comprehensive</td>
<td>Foot deformation</td>
<td>8 d</td>
<td>0 0 0 0 0 0</td>
<td></td>
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<tr>
<td>Cn 4</td>
<td>17/m</td>
<td>Comprehensive</td>
<td>Perthe’s disease</td>
<td>7 d</td>
<td>0 0 0 0 0 0</td>
<td></td>
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<tr>
<td>Cn 5</td>
<td>13/f</td>
<td>Grammar</td>
<td>Leg shortening</td>
<td>8 d</td>
<td>0 0 0 0 0 0</td>
<td></td>
</tr>
<tr>
<td>Cn 6</td>
<td>12/f</td>
<td>Comprehensive</td>
<td>Dysplasia femoral head</td>
<td>7 d</td>
<td>0 0 0 0 0 0</td>
<td></td>
</tr>
<tr>
<td>Cn 7</td>
<td>10/f</td>
<td>Primary</td>
<td>Dysplasia femoral head</td>
<td>7 d</td>
<td>0 0 0 0 0 0</td>
<td></td>
</tr>
<tr>
<td>Cn 8</td>
<td>12/m</td>
<td>Comprehensive</td>
<td>Perthe’s disease</td>
<td>8 d</td>
<td>0 0 0 0 0 0</td>
<td></td>
</tr>
<tr>
<td>Cn 9</td>
<td>12/f</td>
<td>Comprehensive</td>
<td>Perthe’s disease</td>
<td>7 d</td>
<td>0 0 0 0 0 0</td>
<td></td>
</tr>
<tr>
<td>Cn 10</td>
<td>18/m</td>
<td>Commercial</td>
<td>Leg shortening</td>
<td>8 d</td>
<td>0 0 0 0 0 0</td>
<td></td>
</tr>
</tbody>
</table>

Cb, cerebellar; cn, control; f, female; m, male; preop, prior surgery; m, month(s); w, week(s); d, day(s); ataxia score, WFN- ataxia score (Trouillas et al. 1997); TS, total score; maximum, 100; subscores: PG, posture and gait (maximum = 34); UL, kinetic function upper limb (maximum = 36); LL, kinetic function lower limb (maximum = 16); SP, speech (maximum = 8); OC, oculomotor (maximum = 6); extracerebellar, extracerebellar signs; II, optic nerve; VI, abducens nerve; VII, facial nerve; VIII, cochlear nerve; hyperreflex, reflex hypermetria; (r), right; (l), left. *Testing/ MR scan, **accidental finding, ***time since onset cerebellar hemorrhage.
Neuropsychological tests

As a reliable measure of intelligence, the colored progressive matrices test (CPM) without time restrictions was used (Raven 1956). The CPM is a short version of the standard progressive matrices test (SPM) and recommended for children. Patterns of increasing complexity are shown with one segment missing. Subjects have to choose the missing segment out of four possibilities. The absence of time restrictions minimizes the potential influence of the patient’s motor performance deficits on the IQ. The CPM was used in all except one cerebellar child (ch 4) and three control children (cn 3, cn 4, cn 5) in whom the SPM was used. Percentiles (means ± SD) were not significantly different between the patients (56.8 ± 26) and the controls (69.9 ± 19.4; P = 0.2; unpaired t-test). Similarly there was no difference comparing IQ between groups (controls: 108 ± 8.4; cerebellar: 104 ± 13; P = 0.46).

To control the influence of oculomotor performance deficits, a subtest of a German computerized neuropsychological battery for evaluating attention deficits was carried out (Zimmermann and Fimm 1992). The subtest was a visual scanning task in which the subject had to decide and respond as quickly as possible whether or not a specific stimulus occurred in a visually presented matrix. The total number of 100 trials in the original test was reduced to 50 trials. The mean reaction times were calculated for correctly answered trials in which no critical stimulus was in the matrix. This measure was used as an indicator of visual scanning speed because the subjects had to scan the whole matrix in these trials to find the correct answer. Additionally, the number of false reactions was counted. The mean visual scanning time was similar in the patient group [6.3 ± 2.2 (SD) s] and the controls (6.1 ± 1.8; P = 0.9). The number of errors (controls: 2.7 ± 2.1; cerebellar: 3.8 ± 3.4) did not differ between groups (P = 0.4).

Finally, the Sally-Anne test was used (Wimmer and Perner 1983). Through pictures and a story a child’s ability is tested to understand what a person believes. The test can be easily solved by “normal” 5-year-olds but not by autistic children. All children solved the problem without difficulties.

Experimental procedures

Stimuli in two modalities were presented to the subjects. There were two tones (300 and 1,500 Hz) and two visual stimuli (a circle and an ellipse). The high-pitched tone and the ellipse were infrequently presented and the low-pitched tone and the circle were frequently presented. Subjects had to respond with a key press to the infrequently presented stimuli.

There were two tasks, the “focus attention” task and the “shift attention” task (Fig. 1). In the focus attention task, subjects were required to respond to infrequently presented stimuli in one modality while ignoring all stimuli in the other modality. There were two focus attention conditions. During visual focus attention, subjects were instructed to attend to rare visual stimuli (the ellipse) and during acoustic focus attention to the rare acoustic stimulus (the high-pitched tone).

In the shift attention task, subjects were required to respond to the rare target stimulus in one modality and then shift their attention to the rare target stimulus of the other modality, i.e., to respond in turn to the high-pitched tone and ellipse.

In both tasks, the four different stimuli were presented in the same manner. Stimuli were presented one at a time in a pseudorandom order. Stimulus duration was 50 ms, and the interstimulus interval varied between 450 and 1,500 ms (10 equal intervals). The time interval between the rare targets varied between 400 ms and 30 s.

Auditory stimuli were applied bilaterally via headphones. The visual stimuli were presented in the center of a computer screen. The background color was black and stimuli were shown in white. The circle had a diameter of 14 mm and the ellipse a maximum height of 11 mm and a maximum width of 21 mm. All subjects used their preferred hand for responding. The fingers rested on a large single key (4.8 × 4.8 cm). They had to respond with a single key press.

The complete experiment consisted of 20 blocks of 80 stimuli (40 visual and 40 auditory). Ten (25%) of the visual stimuli were ellipses and 30 (75%) circles. Likewise, ten of the auditory stimuli were high-pitched tones and 30 were low-pitched tones. At the beginning of the experiment, the four different stimuli were demonstrated to the subjects. Then subjects performed a practice block of the visual focus attention condition (40 stimuli). This was followed by a maximum of five blocks of the visual focus attention condition. Next subjects performed practice blocks of the acoustic focus attention condition (40 stimuli) and the shift attention condition (40 stimuli). This was followed by a maximum of 10 blocks of the shift attention condition. In each block, subjects responded to the rare acoustic stimulus first. Finally a maximum of five acoustic focus attention blocks had to be performed. The overall correct response rate [(number of hits - number of false alarms)/number of targets * 100] was given after each block on the computer screen for feedback. The time to perform the complete experiment (i.e., 20 blocks of 80 trials) was 45–55 min.

Data analysis

Hits, misses, false alarms, and reaction times were quantified. A correctly detected target was scored as a “hit” if the response occurred
between 150 and 1,400 ms after stimulus onset. Any responses made to a wrong stimulus were counted as false alarms. Lack of response to a target was scored as a “miss.” In the shift condition, when a target item was missed, the next button press to one of the two rare stimuli was scored as a hit and scoring of hits proceeded from there.

If one button press followed two stimuli within the designated time (150–1,400 ms) and one of those two stimuli was the correct target, the button press would be assigned to that target stimulus. Otherwise, the button press would be assigned to the stimulus that occurred first and would be counted as a false alarm.

If a button press followed two target stimuli within the designated time, the button press would be assigned to the second target if the corresponding reaction time was >150 and <1,400 ms. In that case, reaction to the first target would be counted as a miss. If the corresponding reaction time was <150 or >1,400 ms for the second target, the key press would be assigned to the first target and the reaction to the second target would be counted as a miss.

The data were analyzed at different intervals of time elapsed since the onset of each correctly detected target (time since last target, TSLT). Time intervals were chosen putting emphasis on the short target intervals: 0.4–1, 1–2, 2–4, 4–10, and 10–30 s. For comparison, part of data analysis was done using the same time intervals as in Akshoomoff and Courchesne (1992): 0.4–2.5, 2.5–4.5, 4.5–6.5, 6.5–10.5, and 10.5–30 s. Hits, misses and false alarms were expressed as percent of maximum number of targets within each time interval. Reaction times were expressed as means of correctly detected targets within each time interval. Only blocks with 50% correct responses were considered in the statistical analysis. Because there were no performance differences across the subjects between auditory and visual focus attention tasks, the results were collapsed across both types of the stimulus (all P values >0.05).

Imaging

Postoperative standard two-dimensional (2D) MRI scans were available for all children with cerebellar lesions. MRI scans were analyzed that were done at a time most closely related to the time of the experimental testing (Table 1).

Cerebellar lesions and edema seen in the 2D brain images were manually transferred to three-dimensional (3D) MPRAGE images of a healthy adult brain (29-yr-old male) which were spatially normalized to standard stereotaxic brain space according to the Montreal Neurological Institute protocol (MNI space) (Evans et al. 1994) using SPM99 (http://www.fil.ion.ucl.ac.uk/spm/; Wellcome Department of Cognitive Neurology, London, UK). Lesions were drawn onto axial sections of the normalized brain images (voxel size: 3 mm³) using MIRCero (http://www.psychology.nottingham.ac.uk/staff/crl/mircro.html; Rorden and Brett 2000). The extent of the surgical lesion was drawn onto the 3D brain images based on T1-weighted MR images with contrast agent and the extent of the edema based on T2-weighted MR images.

After transferring the individual lesion onto the stereotaxically normalized brain, the extent of the lesion and edema was assessed based on 3D space (i.e., MNI) coordinates. The affected cerebellar lobules and nuclei were defined according to the 3D MRI atlas of the human cerebellum introduced by Schmahmann et al. (2000) and the 3D MRI atlas of the human cerebellar nuclei published by our group (Dimitrova et al. 2002).

Lesions of vermis, paravermis, and lateral hemispheres were considered separately. Sagittal divisions were defined according to Luft et al. (1998). The lateral extent of the vermis was defined by parasagittal planes crossing through the indentation between vermis and tonsils. In the present normalized brain template, the corresponding x range was −10 to +10 mm. The paravermis was defined as 25% of maximum lateral extent of the hemispheres and the lateral hemispheres as the remaining 75%. Based on these measures, an x range of −10 to −24 mm (left) and +10 to +24 mm (right) corresponded to paravermal areas, and x ranges of −24 mm (left) and +24 mm (right) to the outmost left and right to the lateral hemispheres.

R E S U L T S

Imaging

Figure 2 shows both the extent of the surgical lesion (orange) and the edema (violet) for each individual patient superimposed on axial MR images of the healthy subject. The affected cerebellar lobules and nuclei are summarized in Table 2. Examination of MR scans showed no extracerebellar lesions and no signs of hydrocephalus. Parts of the neocerebellum were affected by lesion and/or edema in all children except cb 8. In cb 8, the lesion was restricted to the inferior cerebellar vermis. Parts of the neovermis (vermal lobules VI and VII) were affected in eight children (cb 1, cb 3, cb 4, cb 5, cb 6, cb 7, cb 9, cb 10). The right lateral cerebellar hemisphere was affected in three children (cb 2, cb 5, cb 7). Parts of the cerebellar nuclei were affected in all but one child (cb 7). Dentate nuclei were affected to various degrees in eight children, interposed nuclei in seven children, and fastigial nuclei in seven children.

Based on the extent of the surgical lesion alone, parts of the neocerebellum (i.e., cerebellar hemisphere and/or neovermis and/or dentate nucleus) were affected in all but two children (cb 3 and cb 8).

Attention task

PERCENTAGE OF HITS. On the group level the ability of target detection (percent hits, PHITS) did not significantly differ in the children with cerebellar lesions compared with the control children in both the focus and the shift attention task (Fig. 3). The ability of target detection was significantly better in the focus compared with the shift attention task (task effect P < 0.001; ANOVA with repeated measures). The ability of target detection was smallest in the shortest time interval since last correct target detection (TSLT effect P < 0.001). The effect of short TSLT was more pronounced in the shift compared with the focus attention task (TSLT by task interaction effect P < 0.001). Comparison of the cerebellar group (●) and the control group (□) showed no difference except a small one in target detection in the shortest TSLT. In the 0.4- to 1-s interval, the group mean appeared to be less in children with cerebellar damage compared with controls. The difference, however, was <10% and present in both the focus and the shift attention task (mean ± SD, focus: controls: 98.1 ± 3.8%, cerebellar: 91.5 ± 10.6%; shift: controls: 67.6 ± 14.0%, cerebellar: 59.3 ± 21.3%). The difference did not reach statistical significance. There were no significant group (P = 0.54), group by TSLT (P = 0.19), group by task (P = 0.93), and group by task by TSLT interaction (P = 0.92) effects. Similar results were observed in the subgroups of patients with surgical lesions and/or edema of the neovermis (n = 8; see Imaging) and with surgical lesions of the neovermis (n = 6; cb4–cb7, cb9, cb10). Statistical analysis based on time intervals used by Akshoomoff and Courchesne (1992) revealed similar results.

For comparison, the data were reanalyzed according to Ravizza and Ivy’s study (2001). PHITS were compared in
trials with short time intervals and all other trials with longer interstimulus intervals. Analysis performed with short time intervals of <2.5 s and long time intervals of ≥2.5 s revealed significant task ($P < 0.001$) and TSLT ($P = 0.015$) effects, but no significant group ($P = 0.84$), task by TSLT ($P = 0.10$), task by group ($P = 0.81$), TSLT by group ($P = 0.30$), and task by TSLT by group ($P = 0.62$) interaction effects. Separate analyses for both groups revealed a significant task effect in both groups ($P$ values <0.001). TSLT effect was significant in the cerebellar group ($P = 0.024$) but not the control group ($P = 0.28$). There was, however, no significant task by TSLT interaction in the cerebellar group ($P = 0.49$) indicating that PHITS tended to be smaller in the short time interval in both the focus and the shift task (Fig. 4A). In the controls, TSLT by task interaction was close to statistical significance ($P = 0.078$), indicating that PHITS tended to be smaller in the short time interval in the shift task. Results were not different comparing PHITS in the short time interval of <1 s and longer time intervals of ≥1 s (Fig. 4B).

Inspection of individual data revealed no consistent results (Fig. 5). In the shift task, five cerebellar children (cb 1, cb 2, cb 3, cb 6, cb 9) performed worse in the shortest TSLT with three of them performing better in the 1- to 2-s time interval compared with their matched controls. One of the patients (cb

FIG. 2. Surgical lesions (orange) and surrounding edema (violet) superimposed for each of the 10 children with cerebellar damage on axial stereotaxically normalized MR images of the cerebellum of a healthy subject. Slices are 8 mm apart with the most caudal slice on the left ($z = −60$ mm) and the most cranial slice on the right ($z = −12$ mm). [MR images of the healthy subject were acquired using a T1-weighted magnetization prepared rapid-acquisition gradient echo (MPRAGE) sequence.]
2) had a lesion of the right cerebellar hemisphere, the other four primarily of the vermis (see Table 2 and Fig. 2). The other five patients, however, performed either better ($n/H11005 4$) or equal compared with the controls in the shortest TSLT, with the control performing better in the 1- to 2-s time interval in two subjects. Two of the patients ($cb 5, cb 7$) had a lesion primarily of the right cerebellar hemisphere, the other three a lesion of the vermis ($cb 4, cb 8, cb 10$).

### Percentage of false alarms

Both control children and children with cerebellar lesions had problems when nontarget stimuli occurred ≤1 s after a

<table>
<thead>
<tr>
<th>Subject</th>
<th>Vermis</th>
<th>Paravermis</th>
<th>Hemispheres</th>
<th>White matter</th>
<th>Nuclei</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Cb 1$</td>
<td>V, VI, VIIA, VIIIB, IX, X</td>
<td>L: V, VI, CrII, VIIIA, VIIIB, IX</td>
<td>V3, V1,2,3</td>
<td>ND 1</td>
<td></td>
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<tr>
<td>$Cb 2$</td>
<td>VIIIB, VIIIA, VIIIB, IX, X</td>
<td>R: III, IV, V, VI, VIIA, CrI, CrII, VIIIA, VIIIB, IX, X</td>
<td>R: PV1-3, LH1-3</td>
<td>ND r</td>
<td></td>
</tr>
<tr>
<td>$Cb 3$</td>
<td>VIIIB, VIIIA, VIIIB, IX, X</td>
<td></td>
<td>V2,3</td>
<td>(ND b)</td>
<td></td>
</tr>
<tr>
<td>$Cb 4$</td>
<td>(V, VI, VIIA, VIIIB), VIIIA, VIIIB, IX, X</td>
<td></td>
<td>R: (V2)</td>
<td>ND r</td>
<td></td>
</tr>
<tr>
<td>$Cb 5$</td>
<td>I, II, (III, IV), V, VI, VIIA, IX, X</td>
<td>R: IV, V, VI, VIIIA, VIIIB, IX</td>
<td>V1,2,(3)</td>
<td>ND b</td>
<td></td>
</tr>
<tr>
<td>$Cb 6$</td>
<td>I, II, III, IV, V, VI, VIIA, VIIIB, VIIIA, VIIIB, IX, X</td>
<td>L: (VI)</td>
<td>R: PV1,2, LH1,2</td>
<td>ND b</td>
<td></td>
</tr>
<tr>
<td>$Cb 7$</td>
<td>V, VI</td>
<td>R: V, VI, CrI</td>
<td>V3</td>
<td>NF 1</td>
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<tr>
<td>$Cb 8$</td>
<td>IX, X</td>
<td>L: IX, X</td>
<td>L: PV3</td>
<td>ND b</td>
<td></td>
</tr>
<tr>
<td>$Cb 9$</td>
<td>(VI), VIIA, (VIIA), VIIIB, VIIIA, VIIIB, IX, X</td>
<td></td>
<td>V2,3</td>
<td>(ND b)</td>
<td></td>
</tr>
<tr>
<td>$Cb 10$</td>
<td>(III, IV, V), VIIB, VIIIA, VIIIB, IX, X</td>
<td>R: (VIIIA, VIIIB), IX</td>
<td>V1,2,3</td>
<td>NF b</td>
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</tbody>
</table>

Affected lobules are given separately for the vermis, paravermis and lateral hemispheres (for details see METHODS). Extent of surgical lesions are given in roman letters and of edema in italics. Subdivisions of white matter: V, vermis; PV, paravermis; LH, lateral hemispheres; in V and PV suffix 1 refers to white matter of lobules I–V, 2 of lobules VI–VII and 3 of lobules VIII–X. ND, dentate nucleus; NI, interposed nucleus; NF, fastigial nucleus; R, right; L, left; B, bilateral.

![FIG. 3. Mean percentage of correct target detection (PHITS) and SD in the cerebellar (●) and the control (□) group in the focus (left) and shift (right) attention task. PHITS are shown for the 5 different time intervals as defined in the present study (0.4–1, 1–2, 2–4, 4–10, and 10–30 s; A) and, for comparison, as used by Akshoomoff and Courchesne (1992) (0.4–2.5, 2.5–4.5, 4.5–6.5, 6.5–10.5, and 10.5–30 s; B).](image)
Correctly detected target in both the focus and the shift attention task (mean percentage of false alarms ± SD: focus: controls: 162 ± 60%, cerebellar: 144 ± 40%; shift: controls: 59 ± 21%, cerebellar: 67 ± 14%; Fig. 6A). False alarms were significantly less frequent if the time since last target was >1 s (focus: controls: 1.2 ± 1.2%, cerebellar: 3.8 ± 3.2%; shift: controls: 3.9 ± 2.7%, cerebellar: 4.6 ± 3.5%). The task, TSLT, and task by TSLT interaction effects were significant (P values <0.001). There were no significant group, by task, group by TSLT and group by task by TSLT interaction effects (all P values >0.4). Statistical findings did not differ based on TSLT intervals used by Akshoomoff and Courchesne (1992).

**Reaction times**

Overall, reaction times did not significantly differ when groups, tasks and time intervals (TSLT) were compared (Fig. 6B). There was a tendency of reaction times to be longer in the shift compared with the focus attention task in both the control and cerebellar group (mean reaction time ± SD: focus: control group: 425 ± 59 ms, cerebellar group: 444 ± 85 ms; shift: controls: 441 ± 52 ms, cerebellar: 470 ± 71 ms). In addition reaction times tended to be larger in the cerebellar compared with the control group (mean reaction time: control group: 433 ± 48 ms, cerebellar group: 457 ± 74 ms). There were no significant differences comparing tasks (P = 0.098), TSLT (P = 0.70), TSLT by task (P = 0.12), and groups (group, by task, group by TSLT, group by TSLT by task interaction effects all P values >0.3). Statistical findings did not differ based on TSLT intervals used by Akshoomoff and Courchesne (1992).

In the cerebellar group, reaction time was somewhat related to PHITS in the shortest time intervals (TSLT <1 s; R = 0.47, P = 0.17; linear regression analysis), but not in longer time intervals (1–2 s: R = 0.07, P = 0.85; <2.5 s: R = 0.28, P = 0.44).

**Overall performance**

Six of the 10 cerebellar children and nine of the 10 control children were able to perform all of the required blocks. Both in the control and cerebellar group the correct response rate did not reach the criterion of 50% in all blocks. In the cerebellar group, the criterion was reached on average in 7.3 ± 2.95 blocks in the focus task and in 5.4 ± 2.7 blocks in the shift task. In the control group, the criterion was reached on average in 9.2 ± 1.3 blocks in the focus task and in 6.7 ± 2.36 blocks in the shift task. ANOVA with number of blocks as dependent measure, task (focus vs. shift) and overall performance (blocks performed vs. criterion reached) as within subject factors and group (controls vs. cerebellar) as between subject factor, revealed a group effect close to significance (P = 0.062), a significant difference between the tasks (P = 0.001), a significant task by performance effect (P < 0.001), but no task by group (P = 0.49), performance by group (P = 0.88) or task by performance by group interaction effects (P = 0.68). Thus in both the controls and children with cerebellar lesions the number of blocks which reached the criterion was significantly less in the shift task.

Analysis of PHITS was repeated with the same number of blocks of the patients and their matched controls being entered into statistical analysis, i.e., surplus blocks in the control subjects were discarded. Again, there were no significant differences comparing groups (P = 0.13) and no significant group by task (P = 0.25), group by TSLT (P = 0.13), or group by task by TSLT interaction (P = 0.96) effects.

**Discussion**

The present findings suggest that the cerebellum may be less critical in shifting attention than suggested previously (Courchesne and Allen 1997). In our group of 10 children with cerebellar lesions, the ability of rapidly shifting attention in a time interval <2.5 s was not significantly different compared with the control children. In the time interval <1 s, there was a tendency of children with cerebellar damage to perform worse than the control children. This tendency, however, was not significant in the main ANOVA and was present in both the focus and shift tasks. Although reaction times were only slightly longer in cerebellar children compared with controls, they may still have used more attentional resources to perform the motor part of the task (i.e., pressing the response key) (Helmuth et al. 1997; Timmann et al. 2002). This may have reduced the resources to perform the attention part of the tasks particularly within the shortest time intervals. Unspecific effects of generally reduced attention (e.g., due to headache, depressed mood) are another explanation given that six children were tested within 1–4 weeks after brain injury.

Previous conclusions of impaired shifting attention in children with cerebellar lesions are based on findings in one small

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**FIG. 4.** Mean PHITS and SD in the cerebellar and control group in the focus (left) and shift (right) attention task. PHITS are shown for trials of short time intervals <2.5 s and long time intervals ≥2.5 s (A) as well as for trials of short time intervals <1 s and long time intervals >1 s (B).
FIG. 5. PHITS in each of the ten patients with cerebellar lesions (●) and their matched controls (○). PHITS are shown for the focus (left) and shift (right) tasks and the 5 time intervals (0.4–1, 1–2, 2–4, 4–10, and 10–30 s).
group of subjects (Akshoomoff and Courchesne 1992, 1994; Courchesne et al. 1994). Inspection of individual data suggests that group differences may at least in part be due to findings in a single patient. In Courchesne et al. (1994), the same cerebellar data as in Akshoomoff and Courchesne’s initial paper (1992) are presented in comparison to findings in control and autistic children. Figure 6 (p. 857) shows individual PHITS in the shortest time interval in the shift task in each of the subjects. Findings in three of the six patients with cerebellar damage appear to be within and in two patients little below the normal range. In one patient, PHITS were extremely different and less than the mean $\pm 15$ SD from the control group. Extracerebellar damage in the patient cannot be excluded. Two of the five children with surgical lesions had received cerebral radiation, and the sixth patient with a degenerative disorder has been reported to present with problems in concentration and memory (Akshoomoff et al. 1992).

In a subsequent study, the same five children with surgical lesions were tested using a slightly different paradigm with visual cues only (Akshoomoff and Courchesne 1994). Group differences in shifting attention became significant only after one patient with a lesion not significantly affecting the neocerebellum was removed from analysis. No individual findings are reported.

Differences in study populations and in methods, however, may account for part of the differences between the present and Courchesne’s findings. First reconstructions of the cerebellar lesions in their five patients with surgical lesions (Akshoomoff and Courchesne 1992) show that lesions affected primarily one of the hemispheres in four children and the midline structures of the superior cerebellum in one. In the present group, a larger percentage of affected children had lesions of the posterior and inferior vermis. Results, however, were not different comparing patients with hemispheral and (neo-)vermal lesions.

Another difference between the study populations was age. The mean age in the five children with surgical lesions in Courchesne’s studies both at the time of the testing ($8.6 \pm 1.8$ yr) and at the time of the diagnosis ($5.2 \pm 1.2$ yr) was smaller compared with the present study ($13.1 \pm 2.7$ yr). It cannot be excluded that lesions received at a younger age have a larger impact on the ability to shift attention compared with lesions received at a later age.

We made, however, the experience that the attention span in both control and cerebellar children $<10$ years of age was generally too short to perform a sufficient number of focus and shift blocks. It is not entirely clear why Courchesne and coworkers were more successful in testing younger children. One possible reason is that in the present study subjects had to differentiate between two forms but not colors in the visual domain. However, in their subsequent study, Akshoomoff and Courchesne (1994) reported similar findings in a task where subjects had to shift attention between sensory stimuli of the same visual modality (color and form).

Another difference between studies was amount of training. In Courchesne’s studies all children performed 10 focus attention blocks and as many shift attention blocks until 10 blocks with $\geq 50\%$ correct target detection performance were obtained. In the present study, however, after a brief practice phase, children performed a maximum of 10 blocks each. Both the control children and the children with cerebellar diseases showed...
performed significantly less blocks reaching the criterion of 50% correct response rate in the shift compared with the focus task.

In addition, not all of the affected children were able to perform as many as 10 blocks of each task. Unspecific effects like headache, general fatigue, and depressed mood in the acute cerebellar children are likely reasons of a generally reduced attention span. However, it cannot be excluded that generally reduced attention span was due to cerebellar pathology. Reanalysis using the same number of blocks in children with cerebellar lesions and their matched controls failed to show significant differences comparing the focus and shift attention task. However, because the overall number of blocks was reduced, it cannot be excluded that the statistical power was too small to reveal small differences between groups. In addition, because the cerebellar children performed on average fewer blocks than the control children, one may argue that blocks were biased toward the better blocks in the cerebellar group.

The one other human lesion study using a similar paradigm is that by Ravizza and Ivry (2001) in adult individuals with cerebellar diseases. Findings of their main ANOVA were similar to the present results, i.e., they did not find a significant group effect in rapid shifts of attention. The authors proposed a ceiling effect because of the higher level of performance in their patient group compared with the one of Courchesne and coworkers. Post hoc analysis of cerebellar patients alone revealed a difference in the short time interval comparing the shift and the attention task that was close to significance.

In a subsequent experiment reported in the same paper, Ivry and coworkers reduced the motor requirements of the shifting attention task. They compared performance in a second group of adult patients with cerebellar damage in the original shift task where subjects had to press the response key to each rare stimulus with a shift task where they had to overtly respond to targets in one modality only. The patients showed significantly better performance in the task with less motor requirements in the short time interval.

The authors concluded that deficits seen in the first experiment are likely due to motor performance deficits in cerebellar patients. This view is further supported by a recent fMRI study of the same group using a similar paradigm. Their results show that switching the attention between dimensions without a motor response does not produce stronger cerebellar activation compared with the focus attention condition (Bischoff-Grethe et al. 2002).

Although Allen et al. (1997) showed that different areas were activated in the cerebellum during a pure motor control task (hot spot in the anterior cerebellum) and a pure attention task (hot spot in the posterior cerebellar hemisphere), cerebellar activation may still be due to motor performance in the attention task. In the pure attention task, subjects did not have to press a response button but had to count the rare stimuli. Inner speech is known to activate the posterior cerebellar hemisphere (Wildgruber et al. 2001). Furthermore, Allen et al. (1997) used a focus but not a shift attention paradigm. Based on Courchesne’s initial findings of unimpaired focus attention in cerebellar children, attention-related cerebellar activation during the focus task appears unexpected. In the fMRI study by Le et al. (1998), the contrast of a shifting attention minus a focus attention condition revealed significant activation in the lateral cerebellar hemisphere. No covert shifting attention condition was investigated and findings do not exclude Ivry’s proposal of response reassignment.

Based on the present findings and a review of previous human lesion and fMRI studies, the involvement of the cerebellum in shifting attention may be less than previously assumed. Likewise, results of Townsend et al. (1996, 1999) on deficits in spatial attention in adult patients have been challenged by Yamaguchi et al. (1998) and Golla et al. (2001).

Differences in findings between the present and previous human lesion studies may be explained at least in part by differences in the severity of motor performance deficits. In the initial study by Akshoomoff and Courchesne (1992), reaction times were significantly longer in the children with cerebellar damage compared with controls. In the present study, however, there was no significant difference comparing reaction times in both the focus and shift attention task between affected and healthy children. Lack of significant motor impairment may explain why no deficits in shifting attention were observed in the present group of children with cerebellar lesions.

In summary, the present study was unable to replicate previous findings that children with focal cerebellar lesions are impaired in rapidly shifting attention. Findings suggest that the cerebellum may be less critical in shifting attention than previously assumed.

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