The Relationship of Prone Extension to Other Vestibular Functions
(sensory integration, posture, reflex)

Anita C. Bundy

The purpose of this investigation was to examine clinical observations hypothesized to reflect vestibular integrity in children in an attempt to clinically separate otolithic from semicircular canal functioning. Based on the assumption that prone extension is an otolithic function, two experimental groups and one control group were identified; the groups had varying abilities for prone extension. Using a discriminant analysis, four variables (equilibrium sitting, equilibrium kneeling, eyes crossing the midline, and teacher's impression) were found to predict group membership. Only equilibrium sitting by itself was significantly different between groups. The variables selected by the analysis were originally hypothesized to measure semicircular canal functioning. This was thought, at least in part, to reflect insensitivity of scoring and/or lack of validity of the variables measured. Descriptively, tentative support existed for a division of static from dynamic vestibular function. Therefore, further study is indicated.

Anne G. Fisher

Ayres (1) has hypothesized that the vestibular system plays a role in efficient cognitive learning by contributing to the development of hemispheric specialization. Thus a thorough evaluation of the vestibular system is crucial to the treatment of the learning-disabled child. Ayres (1, 2) has described children who exhibit vestibular dysfunction as having abnormal postrotary nystagmus (PRN) as measured by the Southern California Postrotary Nystagmus Test (SCPNT) and poorly developed postural ocular responses (including prone extension, equilibrium responses and ability to cross the midline with the eyes). However, because of its unreliability, Ottenbacher (3) believed that therapists placed too much weight on the results of the SCPNT while possibly underemphasizing the importance of other clinical evaluations. Both Ottenbacher and Ayres (4) have cited examples of children who had depressed PRN scores, but varying degrees of ability on other vestibularly related clinical observations.

Anatomically, the vestibular receptors have been divided into two categories, static (otolithic) and dynamic (semicircular canal), which work together to provide postural regulation. These receptors, through efferent connections with intratrusal and extratrusal muscle fibers, activate postural responses of both a static (tonic) and dynamic (phasic) nature (5). If the vestibular system can be anatomically divided into static and dynamic components, is it possible that there are children who have dysfunction of only one of these components? Is it also possible that certain clinical observations made by therapists can be more readily attributable to one or the other of the receptors? If so, then perhaps Ayres' (4) and Ottenbacher's (3) observations could be partially explained by such a division.

There is some support in the literature for this speculation. Experimentally, Nashner (6), an aeronautical engineer, was able to differentiate otolithic from semicircular canal functioning. His subjects, three normal adults and one adult with bilaterally transected eighth cranial nerves, were asked to stand on a platform having 2 degrees of freedom of movement. Nashner then measured the "ankle reaction torque" and body angle of each
subject as he alternately eliminated feedback from vision and the exteroceptive mechanism (pressure and feedback from vision and the exteroceptive mechanism). On the basis of his observations in this experiment, he paired the semicircular canals with the exteroceptive mechanism and demonstrated their low threshold, rapid (frequencies greater than 0.1 Hz) detection of body sway. He attributed high threshold, slow (frequencies less than 0.1 Hz) correction, to the otolith organs and the visual system. Thus, he maintained that the semicircular canals are responsible for the immediate correction of posture as the body begins to fall. The design of the semicircular canals makes them unable to respond to static, low frequency conditions. The otoliths, which are sensitive to both static conditions and linear accelerations, receive ambiguous information at high frequencies and require additional processing in order to respond.

If Nashner's (6) theory is correct, the speed of the response demanded may be the basis for dividing clinical observations into semicircular canal function and otolithic function. Ayres (2, 4) has described postrotary nystagmus and prone extension in such a manner that they apparently reflect dynamic and static aspects of vestibular functioning, respectively. Muscle tone, cocontraction, equilibrium reactions, and eye pursuits have all been studied by theorists and researchers and each has been attributed to the vestibular mechanism (2, 5, 7-12). On the basis of Nashner's model, cocontraction and muscle tone may be considered to be primarily static in nature while equilibrium reactions and eye pursuits are primarily dynamic.

Certain implications for the treatment of vestibular dysfunction follow from the differentiation of static from dynamic vestibular function. To normalize the vestibular mechanism, Ayres (2) advocated the use of controlled stimulation in many positions and through many activities to stimulate all possible receptors. If it were known that a child's vestibular dysfunction was primarily static or dynamic in nature, then treatment could center on stimulating the particular receptors responsible for the deficient function, thus making therapy more efficient.

Therefore, the purpose of this investigation was to evaluate a group of normal children on certain clinical observations that have been attributed to vestibular functioning to see how these observations relate to the prone extension posture. Four hypotheses were tested: 1. There will be a significant difference in equilibrium (sitting and kneeling), standing balance with the eyes closed, cocontraction, muscle tone, postrotary nystagmus, ability to cross midline with the eyes, and teacher's impression of overall academic performance between children who are able to assume and maintain a good prone extension posture for 20 seconds who have "normal" scores in equilibrium (sitting and kneeling), standing balance with eyes closed, muscle tone, cocontraction, PRN, or the ability to cross the midline with the eyes. 4. There will be children among those who are unable to assume and/or maintain the prone extension posture for 20 seconds who have "definitely deficient" scores in equilibrium (sitting and kneeling), standing balance with eyes closed, muscle tone, cocontraction, PRN, or the ability to cross the midline with the eyes.

If these hypotheses are supported, they will reinforce the need for careful evaluation of vestibular dysfunction in order that children might receive optimum benefit from treatment.

**Method**

This investigation was carried out in two parts, an initial screening and a testing phase. All children without history of orthopedic, neurological, or seizure disorders enrolled in the first and second grades of three elementary schools in Benton Harbor, Michigan, participated in the initial screening. All 345 children who participated in the initial screening were black. Following verbal instruction and demonstration, the children were asked to assume and maintain the prone extension position. The patterns of prone extension were observed by three registered occupational therapists (intrater reliability 0.9 on 10 subjects). The children were placed in one of five descriptive categories based on the initial screening. The categories were as follows (3 = normal, 2 = slightly deficient, 1 = definitely deficient):

**Table 1**

<table>
<thead>
<tr>
<th>Group</th>
<th>Age Range</th>
<th>Mean Age</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>7-0 to 8-2</td>
<td>7-4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>II</td>
<td>6-11 to 8-8</td>
<td>7-8</td>
<td>21</td>
<td>11</td>
</tr>
<tr>
<td>III</td>
<td>6-10 to 8-9</td>
<td>7-8</td>
<td>21</td>
<td>12</td>
</tr>
</tbody>
</table>

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Table 2
Scoring Criteria for Dependent Variables

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Normal</td>
<td>(3) Presence of three characteristics</td>
</tr>
<tr>
<td>2</td>
<td>Slightly Deficient</td>
<td>(2) Presence of two characteristics</td>
</tr>
<tr>
<td>1</td>
<td>Definitely Deficient</td>
<td>(1) Presence of one or none of characteristics</td>
</tr>
</tbody>
</table>

3. Cocontraction. 
   **Position:** Quadruped 
   Characteristics Observed: 
   (a) Full elbow extension, no locking 
   (b) Absence of lordosis 
   Criteria for scoring: 
   (3) Presence of two characteristics 
   (2) Presence of one characteristic 
   (1) Presence of no above characteristics
4. Muscle Tone. 
   **Position:** Standing 
   Characteristics Observed: 
   (a) Absence of backkneeing 
   (b) Absence of hyperextended elbows 
   Criteria for scoring: 
   (3) Presence of two characteristics 
   (2) Presence of one characteristic 
   (1) Presence of no above characteristics
5. Equilibrium. 
   **Position:** Long-sitting, kneel-stand on an inflatable 
   Characteristics Observed: 
   (a) Extension and abduction of limbs 
   (b) Immediate and spontaneous weight-shift to the uphill side 
   (c) Trunk rotation 
   Criteria for scoring: 
   (3) Presence of three characteristics 
   (2) Presence of two characteristics 
   (1) Presence of one or none of characteristics
6. Eyes Crossing the Midline. 
   **Position:** Seated in small, straight-backed chair 
   Characteristics Observed: 
   (a) Absence of midline jerk in horizontal direction 
   (b) Absence of midline jerk in vertical direction 
   (c) Absence of midline jerk in diagonal direction 
   Criteria for scoring: 
   (3) Presence of three characteristics 
   (2) Presence of two characteristics 
   (1) Presence of one or none of characteristics
   Criteria for scoring: 
   (3) Above average 
   (2) Average 
   (1) Below Average

Elbows on the mat most of the time 
Not able to talk or talks with great effort while maintaining the posture.

One control group (Group III) and two experimental groups (Groups I and II) totaling 72 children were identified from those children who participated in the initial screening. Group III was a random sample of 33 children whose prone extension pattern was described by category 3. The children were matched to Group II for age and sex. Group II was composed of 32 children whose prone extension pattern were described by category 2b. Group I was composed of 7 children whose prone extension patterns were described by category 1b. The breakdown of age and sex for each group is reported in Table 1.

After receiving consent from their parents, children in both the experimental and control groups were seen individually for the testing phase. Testing consisted of observa-
tions of the seven dependent variables: equilibrium reactions in sitting and kneeling, standing balance with eyes closed, muscle tone, cocontraction, ability of the eyes to cross the midline, and PRN. Testing procedure was based on common clinical practice among sensory integrative trained therapists: three characteristics were selected as criteria for each of the observed functions. Each child received a score of 1, 2, or 3 for each of the observations depending on the number of characteristics exhibited. The order of testing was randomized to control for the effects of fatigue, interest, and cumulative vestibular stimulation. In addition, an eighth dependent variable was identified: the children's teachers were asked to rate each child's overall academic performance on a 3-point scale, with 3, above average; 2, average; and 1, below average.

The testing phase was carried out by the principal examiner and an assistant. The procedure is listed in the appendix.

Results
A stepwise discriminant analysis, using all eight dependent variables, and univariate t tests, using those dependent variables that generated interval or ratio data (age, PRN, standing balance eyes closed), revealed that only one dependent variable by itself, equilibrium sitting, could significantly discriminate (at the p = .05 level) between the three groups of children. Thus all parts of the hypothesis that predicted significant differences in the children's scores on the other vestibular measures according to their abilities to do prone extension were rejected except for equilibrium sitting, which was confirmed.

The discriminate analysis identified four dependent variables, which when considered together could be used to predict a child's group membership. These four variables in order of their greatest contribution include equilibrium sitting, equilibrium kneeling, eyes crossing the midline, and the teacher's impression of the child's overall academic performance. The relative contributions of each of these variables are described in Table 2. Equilibrium sitting and kneeling form the majority of the discriminate function. Equilibrium kneeling and teacher's impressions both have negative correlations. Based on the four dependent variables identified by the discriminate analysis, the group membership of 58.3 percent of the children tested was correctly predicted (see Table 3). Chance alone would have predicted 33.3 percent. Thus the four variables identified by the discriminate function are only fair predictors of group membership.

The data were also analyzed descriptively. Of the 33 children able to maintain a good prone extension posture (Group III), 12 scored "definitely deficient" on the criteria describing at least one dependent variable measured and 34.8 percent had an abnormal PRN score. Thus the hypothesis that some children who were able to maintain a good prone extension pattern would score poorly on other vestibular measures was confirmed.

Each of the 32 children who required excessive effort to maintain prone extension (Group II) scored within normal limits on at least one variable (including 30 percent with normal PRN), as did 6 of the 7 children who were unable to assume prone extension (Group I). Thus the hypothesis that some children unable to do prone extension would score within normal limits on other vestibular measures was confirmed.

Table 4 reports the frequency of the scores of each of the dependent variables for each of the three groups.

Discussion
Based on Nashner's (6) model, this investigation predicted that muscle tone and cocontraction would discriminate between groups. The reason that equilibrium sitting, equilibrium kneeling, eyes crossing the midline, and teacher's impression were found to be the best predictors is unclear.

The vestibular mechanism influences extensor rather than flexor muscle tone (3), yet it was the flexor muscles that were tested when the limbs were evaluated for hyperextensibility. Therefore, in retrospect, the evaluation of muscle tone may not have reflected the vestibular aspect of this function. Furthermore, it seems likely that hyperextensibility of joints is not a valid measure of muscle tone; several children, who on palpation felt quite hypotonic, obtained a normal score on muscle tone (i.e., they neither backkneed nor had hyperextended elbows).

The method in which cocontraction was evaluated in this investigation is also likely to be invalid, because, according to Basmajian...

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Table 3
<table>
<thead>
<tr>
<th>Standardized Canonical Discriminant Function Coefficients*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyes Crossing Midline                                      0.47484</td>
</tr>
<tr>
<td>Equilibrium Sitting                                        1.26564</td>
</tr>
<tr>
<td>Equilibrium Kneeling                                       -1.12628</td>
</tr>
<tr>
<td>Teacher's Impression                                       -0.20829</td>
</tr>
</tbody>
</table>

*Interpretation of numbers is analogous to interpretation of beta weights in multiple regression analysis and (without the signs) represent the relative importance of each of the variables. The signs determine whether the contribution is negative or positive.

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Table 4
<table>
<thead>
<tr>
<th>Discriminant Analysis Classification Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Group</td>
</tr>
<tr>
<td>--------------</td>
</tr>
<tr>
<td>I</td>
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<tr>
<td>II</td>
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<tr>
<td>III</td>
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</table>

Percent of "grouped" cases correctly classified = 58.3 percent. Italics indicate cases correctly classified.
cocontraction does not always occur in weight-bearing positions.

If the criteria used in measuring cocontraction and muscle tone were not valid measures or did not reflect the vestibular aspects of those functions, this may be the reason they did not appear in the analysis as discriminating factors. However, this does not explain why equilibrium sitting and kneeling were the best predictors of group membership. A closer look at the manner in which equilibrium sitting and kneeling were evaluated revealed a possible explanation. Maintaining prone extension, in Ayres' (1) opinion, resulted from impulses conveyed via the vestibulospinal tract, and was therefore assumed in this investigation to be a static vestibular function. In retrospect, prone extension also seems to have an important dynamic component: assumption of the posture. Therefore, based on their performance of prone extension, the children in group III had normal dynamic and static functioning, i.e., they could assume and maintain prone extension, respectively. The children in Group II had normal dynamic functioning; however, their static functioning was impaired. The children in Group I had impaired dynamic functioning, but nothing is known about their static functioning as no attempt was made to determine if they could maintain the position once placed in it. Because the children in Group II had impaired static functioning and also obtained lower scores on equilibrium sitting, equilibrium sitting may be a static function. When tested, the children sat with a wide base of support and a low center of gravity. Therefore, a wide-range, high-threshold, otolith-detected (6) movement was required before equilibrium was threatened and a reaction was elicited. This is supported by the fact that equilibrium kneeling had a negative correlation in the discriminant function and when equilibrium kneeling was measured, children had a narrow base of support and a high center of gravity. As a result, short-range, low-threshold, semicircular canal-detected (6) movement was all that was required to elicit equilibrium reactions. Thus, equilibrium kneeling seems to be a dynamic vestibular function as measured in this investigation. This is borne out by the observation that Group I, which had the poorest dynamic functioning, also scored the lowest in equilibrium kneeling.

Even if, as discussed above, the evaluations of muscle tone and cocontraction were invalid, the groups were hypothesized to differ significantly on more than one dependent measure. One possible explanation for the failure of any of the other variables to differentiate between groups is that the three-point scale did not allow much latitude and was therefore insensitive to the detection of mild dysfunction. Another

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### Table 5

**Group Scores on Dependent Variables**

<table>
<thead>
<tr>
<th>Group</th>
<th>Prone Extension</th>
<th>Muscle Tone</th>
<th>Cocontraction</th>
<th>PRN</th>
<th>Equilibrium Sitting</th>
<th>Equilibrium Kneeling</th>
<th>Eyes Crossing Midline</th>
<th>Standing Balance (Even Closed)</th>
<th>Teacher's Impression</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GROUP III (N = 33)</strong></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>33</td>
<td>17</td>
<td>21</td>
<td>19</td>
<td>22</td>
<td>18</td>
<td>24</td>
<td>33</td>
<td>7</td>
</tr>
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<td>percent</td>
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<td>52</td>
<td>64</td>
<td>58</td>
<td>67</td>
<td>55</td>
<td>73</td>
<td>100</td>
<td>11</td>
</tr>
<tr>
<td>Slightly Deficient</td>
<td>9</td>
<td>9</td>
<td>hypo</td>
<td>9</td>
<td>10</td>
<td>12</td>
<td>3</td>
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<tr>
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<td>36</td>
<td>9</td>
<td>9</td>
<td>33</td>
<td>3</td>
</tr>
<tr>
<td>Definitely Deficient</td>
<td>7</td>
<td>3</td>
<td>hyper</td>
<td>9</td>
<td>3</td>
<td>3</td>
<td>6</td>
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<td>percent</td>
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<td>9</td>
<td>9</td>
<td>9</td>
<td>18</td>
<td>18</td>
<td>33</td>
<td>3</td>
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<tr>
<td><strong>GROUP II (N = 32)</strong></td>
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<td></td>
<td></td>
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<tr>
<td>Normal</td>
<td>11</td>
<td>17</td>
<td>19</td>
<td>14</td>
<td>14</td>
<td>20</td>
<td>32</td>
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<td>44</td>
<td>63</td>
<td>100</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>Slightly Deficient</td>
<td>32</td>
<td>19</td>
<td>11</td>
<td>2</td>
<td>10</td>
<td>8</td>
<td>3</td>
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<tr>
<td>percent</td>
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<td>6</td>
<td>33</td>
<td>25</td>
<td>9</td>
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<tr>
<td>Definitely Deficient</td>
<td>2</td>
<td>4</td>
<td>hyper</td>
<td>13</td>
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<td>26</td>
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<td>28</td>
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<td><strong>GROUP I (N = 7)</strong></td>
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<td>14</td>
<td>71</td>
<td>96</td>
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<tr>
<td>Slightly Deficient</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
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<td>43</td>
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<td>14</td>
<td>57</td>
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<tr>
<td>Definitely Deficient</td>
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<td>1</td>
<td>hyper</td>
<td>14</td>
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<td>14</td>
<td>43</td>
<td>43</td>
<td>43</td>
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</tr>
</tbody>
</table>
possibility is that prone extension, as evaluated in this investigation, was not a valid measure of static vestibular function. However, according to Wilson (15), more vestibular input is carried via the vestibulospinal tracts to the extensors of the neck and the upper trunk than to the lower trunk. Furthermore, the vestibular system primarily exerts its influence on static gamma motoneurons involved in sustained (tonic) muscle contractions (16). Because Groups I and II were chosen on the basis that the children were unable to initiate or maintain sustained extension of the upper trunk and/or neck, it seems likely that prone extension is a valid measure of static vestibular function. But because no studies have been carried out to establish the validity of prone extension as a measure of vestibular functioning, further research is indicated.

The results of this investigation did not identify, as predicted, a static/dynamic division of clinical observations. Therefore, it is difficult to discuss the significance of the descriptive analysis. However, approximately one-third of the children who demonstrated normal prone extension had abnormal PRN and one-third of the children in Group II who were unable to maintain the prone extension posture had normal PRN. This observation, along with the absence of PRN in the discriminant analysis, may tentatively support a clinical separation of static from dynamic vestibular functioning in children.

Conclusions and Implications

As a result of this study, it was concluded that ability to perform equilibrium sitting, by itself, or in conjunction with an inability to do equilibrium kneeling, ability of eyes to cross the midline, and the teacher’s impression of below average academic performance can be used to predict children’s abilities for prone extension. In addition, children who score poorly on one vestibular measure will not necessarily score poorly on other measures of vestibular function.

Although tentative support existed for a clinical separation of static from dynamic vestibular function, further research is indicated to determine the validity of measures of static vestibular function. Ocular counterrolling (17) and Nashner’s (6) 2 degrees of freedom platform are valid measures of otolithic functioning. Further study should be directed toward determining which clinical measures of vestibular function correlate most highly with one of these valid otolithic measures. Furthermore, considering the possibility that a division exists, therapists should be aware of the manner in which they evaluate vestibular functioning (i.e., wide-range, high-threshold, low-frequency versus short-range, low-threshold, high-frequency responses).

Acknowledgments

Special thanks are extended to Catherine Trombly, M.A., OTR, and Kaye Jeter, Ph.D., for their invaluable assistance and to the children from Bard, Morton, and Seely Mc Cord Elementary Schools in Benton Harbor, Michigan, for their eagerness to participate. This study was completed in partial fulfillment of the requirements for the degree of Master of Science from Sargent College, Boston University. It was funded in part by an Allied Health Professions Traineeship Grant, U.S. Department of Health, Education and Welfare, and by the Dudley Allen Sargent Fund for Research.

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