Poor Postural Stability in Children with Vertigo and Vergence Abnormalities

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PURPOSE. An earlier study suggested that deficits of vergence can influence postural control via the efferent and afferent proprioceptive signals. In this study, postural control in 28 children with vertigo with normal vestibular function but with vergence abnormalities and in 19 normal children of comparable age was assessed with orthoptic tests.

METHODS. A posturography platform was used to examine posture in quiet stance. The child was asked to fixate a target at 40 cm or at 200 cm, either with eyes open (vision condition) or with eyes covered by a black mask (no vision condition). In a complementary test in 15 of 28 children with vertigo and in all 19 normal children, postural control was evaluated during monocular viewing (dominant and nondominant eye viewing).

RESULTS. For all children examined, postural stability was better when fixating a target at near than at far distance and with both eyes than with one eye or with eyes covered. In all conditions, the children with vertigo were more unstable than were the control children.

CONCLUSIONS. Binocular visual information, such as vergence disparity, is essential in stabilizing posture at near distance. Postural instability reported in children with vertigo and vergence abnormalities could be due to poor vergence inputs and/or to immature compensatory mechanisms controlling postural stability (vestibular, somatosensory inputs and/or cerebellar processes). (Invest Ophthalmol Vis Sci. 2009;50: 4678–4684) DOI:10.1167/iovs.09-3537

Vertigo is a symptom that is frequently due to vestibular dysfunction or to visual disorders.1 Anoh-Tanon et al.2 first reported that an increased number of children consulting the ENT (ear, nose, and throat) service for vertigo and headaches showed normal vestibular function but presented signs of vergence abnormalities assessed by orthoptic tests. They pointed out that deficits in vergence could deteriorate gaze stabilization during body movements and thus, cause double or blurry vision that can lead to vertigo and sensation of imbalance. Our group, for the first time, showed, with binocular eye movement recordings in these same types of children suffering vertigo, several oculomotor abnormalities: abnormal longer latency and poor accuracy, particularly for vergence movements, and abnormal large disconjugacy for saccades made at near distance.3–5 Note that the gain of the vestibular–ocular reflex (VOR) is modulated by the viewing distance and the vergence angle.6 Consequently, we suggested that abnormalities of vergence can lead to inappropriate VOR adjustments and thereby poor gaze stabilization and vertigo.7 It is well known that for maintenance of static balance, the central nervous system has to integrate information from the proprioceptive, vestibular, and visual signals.8 Our hypothesis was that deficits of vergence can influence postural control via the efferent and afferent proprioceptive signals, as shown by Kapoula and Lê.7 The first goal of this study was to evaluate postural control in a group of children with vertigo and vergence abnormalities and to compare the results with those obtained from a group of normal children of comparable age without vertigo symptoms.

Furthermore, a complementary study was run to examine postural control during monocular viewing. Indeed, visual cues, particularly depth cues, are different during binocular and monocular viewing9 (for review, see Howard and Rogers). Guerraz et al.9 showed in normal adults that motion parallax improves postural control during binocular as well as monocular viewing (dominant eye viewing) suggesting that motion parallax, monocular or binocular, can give depth information. However, disparity information depends on binocular input—that is, the discrete difference between the images of the objects on retina of each eye—and McKnight et al.10 reported that perception of distance in depth is better with binocular than monocular vision. Sors et al.11 and Magne and Coello12 suggested that the superiority of binocular information for distance evaluation occurs only in active tasks and not in static conditions, but in children (from 5 to 11 years old), it has been shown that the control of prehensile movement persists even when binocular information is removed by patching one eye.13 For static postural control, Gentaz14 proposed in adults the existence of a postural eye (which is not always the dominant eye) which allows stabilization even better than both eyes viewing. Recently, Lê and Kapoula15 showed in adults that distance impairs postural stability only during binocular viewing. They proposed that, during monocular viewing, adults presumably increase their attention, allowing good postural control independent of distance. There have been no studies examining the effect on viewing condition in children, either in normal children or in those with vergence abnormalities.

### Material and Methods

#### Subjects

Twenty-eight children (mean age, 11.2 ± 2.7 years) participated in the study. The children were recruited by the ENT and Ophthalmology Service of the Children’s Hospital because they had symptoms of vertigo and headache. More precisely, the children felt the environment moving around them or felt unbalanced. These symptoms occurred several times during the day, frequently related to fatigue. (at

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Submitted for publication February 9, 2009; revised March 31 and April 16, 2009; accepted July 16, 2009.

Disclosure: M.P. Bucci, None; T.-T. Lê, None; S. Wiener-Vacher, None; D. Brémont-Gignac, None; A. Bouet, None; Z. Kapoula, None.

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school or at the end of the day, and often after long exposure to computer or television screens), and they were usually brief, lasting less than 1 minute. No child had neurologic problems, and none was receiving any medication. All the children underwent complete vestibular and orthoptic examinations as described in our previous articles. Data from the children with vertigo were compared with data from a group of 19 normal children of comparable age (mean age, 11.6 ± 2.2 years) with no vertigo symptoms.

The investigation adhered to the principles of the Declaration of Helsinki and was approved by our Institutional Human Experimentation Committee. Informed consent was obtained from the children's parents after explanation of the procedures involved.

### Vestibular Examination

Vestibular testing was extensive, including a caloric test, a canal and otoolith examination, earth vertical axis rotation, off vertical axis rotation with a computer-controlled rotating chair in the dark, and VEMPs (vestibular evoked myogenic potentials). The inner function was also examined with conventional hearing tests (tonal and speech audiometric techniques). The results of all these tests were normal in all the children participating, excluding any vestibular hypofunction. Consequently, vertigo symptoms reported by the children were not due to vestibular disorders.

### Orthoptic Examination

All children, with and without vertigo, underwent ophthalmic and orthoptic examination to evaluate their visual function. Visual acuity was measured with the children under skiasal (cyclopentolate chlorhydrate 0.5%, a drug inducing temporary paresis of accommodation). One drop was administered to each eye twice, the second drop 10 minutes after the first. Visual acuity was tested 45 minutes after the first drop. It was measured for each eye separately at far (5 m) and near (30 cm) distances with the Hirschberg chart (an optometric chart containing 10 rows of letters, each row corresponding to 1/10 visual acuity) and the Parisaud scale (fragments of text with letters that are gradually smaller), respectively. The stereovisual threshold based on disparity detection was tested with the TNO random dot test for stereoscopic depth discrimination. The measurement of fusalional amplitude of convergence and divergence was done both at far (4 m) and at near (30 cm) distance by using a base-in, base-out prism bar. Divergence amplitude was measured twice, before and after the convergence measure, to evaluate accommodative spasm.

Heterophoria (i.e., the latent deviation of one eye when the other is covered) was measured at both distances (far and near) by using the cover–uncover test and the Maddox rod. The AC/RA ratio was also measured with the heterophoria method. The near point of convergence (NPC) was also examined by placing a small penlight at 30/40 cm in the midplane in front of the face when the child was moving it slowly toward the eyes until one eye lost fixation. Finally, the dominant eye was evaluated by asking the child to look through his or her hands at a target at 5 m and then to close each eye alternatively, to judge the eye for which the alignment was the best.

### Platform

To measure postural stability, we used a platform (principle of strain gauge) consisting of two dynanometric clogs (Standards by Association Francaise de Posturologie, produced by TechnoConcept, Céreste, France). The excursions of the center of pressure (COP) were measured during 51.2 seconds; the equipment contained an analog–digital converter of 16 bits. The sampling frequency of the COP was 40 Hz.

### Procedure

The child was asked to fixate a target along the vertical midline at his or her eye level. The target was a human face, happy or sad (signified by the position of the mouth), displayed on a vertical screen. The angular size of the face was adjusted to subtend 1° for both viewing distances tested (200 and 40 cm). Posturography was performed in a normal furnished experimental room. The child was placed on the platform and was asked to fixate the target face and to note whether the face was happy or sad. The target was placed at either 200 or 40 cm, and it was visible and clear in both distance conditions. Two conditions were run at these two distances: vision (binocular eye viewing, BEV) and no vision (eyes covered by a black mask).

For 15 of the children with vertigo and for all normal children without vertigo, a complementary condition during monocular viewing (DEV, dominant eye viewing and NDEV, nondominant eye viewing) was also recorded. For DEV and NDEV, a black mask was placed over one eye and fixed around the child's head with a rubber band. The order of the distances and of the viewing conditions (BEV, DEV, NDEV, and no vision) was counterbalanced among the children. Each test was separated by a rest of a few minutes.

### Data Analysis

The methods of posture measurement are similar to those used in prior studies. We analyzed the standard deviations of the lateral body sways (SDxs) and of the anteroposterior sways (SDys), the surface area of the COP and the variance in the speed of the COP excursion. The surface area of the COP was calculated so that 90% of the COP was inside an ellipse.

Statistical analysis was performed with a mixed ANOVA, with the two groups of children (19 normal and 28 vertigo) as the between-subject factor and the viewing distance (far and near) and the conditions (vision and no vision) as within-subject factors. In the complementary study, a mixed ANOVA was run, with the two groups of children (19 normal and 15 vertigo) as the between-subject factor and the viewing distance (far and near) and the viewing conditions (BEV, DEV, NDEV) as the within-subject factors. Post hoc comparisons were made with the least significant differences (LSD) test.

### Results

#### Visual Examination

Clinical findings for both groups of children are shown in Tables 1 and 2. All the children had normal visual acuity at both far and near distance (≥20/25), normal binocular vision (60 seconds of arc or better), and normal near point of convergence (≤5 cm). In the control children (see Table 1), phoria and vergence fusional amplitudes at both distances tested were normal. In the majority of the children with vertigo, phoria at far and near distances was also in normal range (according to Morgan findings); in contrast, several children with vertigo had abnormal vergence fusional amplitude. Such vergence abnormalities are based on ophthalmic pediatric references. Recall that vergence disorders are more frequently found in children and they can be responsible for headache, dizziness, and visual disturbances when reading or doing close work. Most likely, prolonged work at the computer and video games increase the sustained fusion effort, which can lead to symptomatic oculomotor disorders and accommodative deficits that were tolerated and compensated before. This sustained fusion effort could explain the high number of vertiginous children (5% or 523 children, during a period of 5 years) referred to the ENT service at the Robert Debré Pediatric Hospital in Paris.2

Children with vertigo (Table 2) were classified in three diagnostic groups showing different signs of vergence insufficiency based on poor convergence or divergence amplitude range, on exophoria at near ≥4 D than at far and on failing Sheard’s criterion (C1) or poor convergence, particularly at far distance (C2–C7). For all these children, the presence of accommodative spams was observed. Recall that accommodative spasm originates in the ciliary muscle, leading to inability of the eyes to relax accommodation and, frequently, to fatigue and headache due to
poor fusional convergence at far and exophoria at both distances (except child C9 for whom esophoria was reported). In the majority of these children, poor convergence at near was also observed; (3) high level of vergence insufficiency due to poor fusional convergence at both distances and exophoria at both distances (C20–C27). Children C21 and C26 also had poor divergence at near and at far distances, respectively. Finally, child C28 showed a poor convergence range, even though his vision was esophoric at both distances.

To improve the range of vergence fusional amplitude, we prescribed orthoptic training for most of the children (23/28); for the remaining five children (C3, C4, C7, C15, and C24) a hypermetropic correction of 0.50 D for both eyes was prescribed at first to see whether this correction of visual acuity would be sufficient to improve the child’s comfort. Note that the purpose of plus lenses was to decrease the demand on the accommodation system and/or to reduce the amount of esodeviation by manipulating the cross-link AC/A ratio.26

<table>
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<th>Convergence (pD)</th>
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![Table 1. Characteristics of Children with No Vertigo Symptoms](image)

![Table 2. Characteristics of Children with Vertigo and Vergence Abnormalities](image)
The ANOVA shows a significant group effect for the SD of the lateral sway \((F_{(1,45)} = 7.82, P < 0.008,\) respectively), the surface area of the COP \((F_{(1,45)} = 8.00, P < 0.008),\) and the variance of speed \((F_{(1,45)} = 12.41, P < 0.001)\) were significantly larger at far than at near distance. There was no association of group and distance.

**Interaction between Distance and Condition**

There was no main effect of the condition (vision versus no vision) on the postural parameters measured. However, there are a significant interaction between distance and condition for the SD of the surface area and the variance of speed of the COP \((F_{(1,45)} = 4.45, P < 0.04,\) and \(F_{(1,45)} = 5.48, P < 0.02,\) respectively). At near distance, the surface area of the COP was significantly smaller in the vision condition \((P < 0.001)\) and the variance of speed was significantly smaller in the vision condition for both distances \((P < 0.01\) for far distance and \(P < 0.001\) for near distance).

**Group Effect: Poor Postural Control in Children with Vertigo**

Values of all parameters of posturography were higher in the children with vertigo than in the normal children. Indeed, the ANOVA showed a significant group effect for all but one parameter measured (the SD of the anteroposterior sway): for the SD of the lateral sway \((F_{(1,45)} = 21.94, P < 0.001)\) and for the surface area and the variance of speed of the COP \((F_{(1,45)} = 5.98, P < 0.02\) and \(F_{(1,45)} = 12.30, P < 0.001,\) respectively). All these parameters were significantly larger in the children with vertigo than in the normal children.

**Complementary Study: Monocular Versus Binocular Viewing**

Postural data from the complementary study examining postural control during binocular versus monocular viewing at far and near distances are shown in Figure 2.

**Distance, Viewing Condition Effect, and Their Interaction**

The distance effect existed for the variance of speed of the COP only \((F_{(1,32)} = 8.18, P < 0.01,\) whereas the effect of viewing was observed for the SD of lateral sway \((F_{(1,32)} = 11.43, P < 0.001)\) and for the surface area and the variance of speed of the COP \((F_{(1,32)} = 3.79, P < 0.04\) and \(F_{(1,32)} = 4.473, P < 0.018,\) respectively). Postural gaze during binocular viewing was significantly better than that measured during monocular eye viewing. Of importance, for most of the postural parameters analyzed, there was an interaction between distance and viewing condition: for the SD of the anteroposterior sway \((F_{(2,64)} = 4.79, P < 0.019)\), for the surface area of the COP \((F_{(2,64)} = 4.03, P < 0.035),\) and for the variance of speed \((F_{(2,64)} = 5.95, P < 0.05).\) A post hoc comparison showed that during BEV, postural stabilization was significantly better at near than at far distance for all these parameters \((P < 0.01).\) In contrast, during monocular viewing (DEV and NDEV) stabilization was similar at both distances, but it was significantly worse than the stability during binocular viewing at near distance only \((P < 0.01).\) In sum, binocular viewing and proximity promote the best postural stability.

**Group Effect**

The ANOVA shows a significant group effect for the SD of anteroposterior sway \((F_{(1,32)} = 4.5, P < 0.05),\) for the surface area of the COP \((F_{(1,32)} = 5.26, P < 0.04),\) and for the variance of speed \((F_{(1,32)} = 13.87, P < 0.001).\) For all postural parameters examined, the children with vertigo...
showed larger values than did the normal children. This result in 15 children with vertigo supports the hypothesis of the study.

**DISCUSSION**

**Distance Effect during Binocular Viewing**

For the first time, Brandt et al.\(^2\) showed that the postural stability is better at near than at far distance, because of the decrease of visual motion signals at far distance. The effect of distance on postural control could be also related to the oculomotor signals themselves, as suggested by our group.\(^7\) Indeed, these authors showed that modification of the vergence angle by wearing convergent prisms alone improves postural stability, even though the real viewing distance is far. Kapoula and Lê\(^7\) proposed that convergence of the eyes at near distance improves the postural stability via efferent and afferent proprioceptive oculomotor signals. This phenomenon was observed also in the present study in normal children (without vertigo symptoms) and in children with vertigo and vergence abnormalities. Their postural stability was better at near than at far distance in the static condition. This result is novel and highlights the importance of the vergence angle. Even when malfunctioning, vergence capabilities help to improve stability at near.

**Interaction between Distance and Vision/No-Vision Conditions**

Another important result of our study is that postural stabilization was worse with no vision. Both the surface and the speed of variance of the COP increased in the no-vision condition. Note that the benefit of vision occurred only when children were tested at near distance. This finding in children extends prior observations in adults showing that it is not the vision per se but the combined action of vision and oculomotor signals of convergence that are responsible for better stabilization at near.\(^7\),\(^2\) Once again, even though malfunctioning, vergence is still important in postural control in children with vertigo.

**Poor Postural Stability during Monocular Viewing at Near Distance Only**

Another important finding of the present study is that postural stabilization was worse during monocular than during binocular viewing at near distance only, as shown by the interaction between viewing distance and viewing condition. In the literature, Fox\(^3\) tested the postural stability during binocular and monocular viewing at far distance (145 cm) and did not find any difference between the two viewing conditions. On the other hand, Isotalo et al.\(^3\) tested the effect of viewing conditions on postural control at closer distance (90 cm) and showed, in half of the subjects only, better stabilization during binocular viewing. Based on all these findings, we suggest that in children the importance of binocular vision in postural control increases with proximity; moreover, children's postural behavior is different from that observed in adults. Indeed, Lê and Kapoula,\(^1\) using experimental conditions similar to those used in the current study, found stability of posture regardless of viewing distance during monocular viewing. During binocular viewing, they observed a deterioration of stability at far distance. In other words, children benefit from binocular vision at near and show no penalty from the absence of binocular vision at far distance; in contrast, adults show no significant benefit at near and a penalty at far distance. We have no explanation for this difference between children and adults. Binocular vision seems to be used more by children than by adults.

The superiority of binocular versus monocular visual inputs is well known (see the introduction), but the novelty is that binocular visual inputs allow a better postural stability at near distance only. We suggest that improvement of posture at near could be due to improved perception of movement in depth, based on changes in binocular disparity; such changes could result from anteroposterior body oscillation and could be used to stabilize the body. At near distance, the angular size of the target (monocular or binocular viewing) is higher, allowing better postural stabilization. Thus, in the presence of multiple perceived visual signals, including better control of oculomotor vergence, children optimize their postural stability at near distance when both eyes are viewing.

Finally, during monocular viewing, one could expect similar postural control for both groups of children given the absence of binocular disparity vergence inputs. However, this was not the case, and any interaction between group and viewing
condition was not reported. Most likely, during monocular viewing, even if disparity vergence inputs are eliminated, monocularly driven vergence inputs (e.g., accommodative vergence, proximal vergence, and vergence induced by monocular depth cues) are still present. We suggest that such inputs are impaired in children with vertigo. Thus, poor postural control in children with vertigo is not only due to abnormalities of binocular disparity vergence but also to monocular vergence inputs.

**Poor Postural Stability in Children with Vertigo and Vergence Abnormalities**

In this study, postural control was impaired in children with vertigo compared with that in normal children. Our sample had normal vestibular function but vergence abnormalities (Table 2). Consequently, based on these clinical measures, we suggest that the postural instability reported herein was not due to reduced vestibular signals but most likely to impaired vergence inputs. The oculomotor deficits clinically assessed in these children with vertigo could deteriorate the quality of visual inputs—for example, reducing the quality of oculomotor vergence signals leading to poor internal proprioceptive feedback mechanism, resulting in poor postural control. Even if proprioception is recognized as the main source of sensory information for balance control on a static surface, recent studies from our group in normal adults suggest that oculomotor vergence signals, including oculomotor proprioception, may play an important role in static postural control. Our results show that this occurs also in children and support the hypothesis that correct vergence information is necessary for good control of posture. Another hypothesis has been proposed by Friedrich et al. They studied with a frequency analysis (Fourier) the postural control in normal and visually handicapped adults. They showed that when visual inputs are deficient, compensation mechanisms, vestibular somatosensory inputs, and cerebellar processes can be activated to assure good postural control. In children and in adolescents with vertigo and vergence abnormalities such compensatory mechanisms may be immature leading to poor postural control. This idea agrees with the hypothesis made by several investigators in developmental studies on dynamic balance control. Indeed, these authors suggested that young children (6–7 years old) had poor control of dynamic posture because they were not able to give equal weight to the three different sensory systems (somatosensory, vestibular, and visual inputs) implicated in dynamic postural control. Such capacity probably is essential for both dynamic and static postural control mechanisms and develops with age.

**Acknowledgments**

The authors thank the children who participated in the study.

**References**