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Vertical phoria and postural control in upright stance in healthy young subjects

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ABSTRACT

Objective: To test the quality of postural performance in quiet upright stance in healthy young adults with vertical heterophoria (VH) within the normal range and without VH (vertical orthophoria, VO).
Methods: Twenty-six subjects took part in this study. The postural stability was measured with a force platform while the subjects fixated a target at eye level in a straight ahead position, placed at either 40 or 200 cm.
Results: The results indicated that the postural control was better for subjects with VO than subjects with VH. Particularly, there was an interaction between vertical phoria and distance: the subjects with VH showed greater instability than the subjects with VO at a far distance only. An additional study showed that the cancellation of VH with a prism improved postural stability.
Conclusions: The quality of postural performance in quiet upright stance was lower in the subjects with VH. We speculate that VH, even when small in size, indicates a perturbation of the somatosensory/proprioceptive loops involved in postural control.
Significance: Vertical phoria could perhaps indicate the capacity of the central nervous system to integrate optimally proprioceptive cues.

1. Introduction

Postural control in quiet upright stance requires the central integration of visual, vestibular, cutaneous and muscle proprioceptive sensory inputs and their rapid processing (Nashner, 1976). To maintain the centre of body mass in equilibrium, the central nervous system performs appropriate coordinate transformations of these inputs (Ivanenko et al., 1999) and permanently generates muscular response adapted as corrective torque through the action of a feedback control system (Horak and Macpherson, 1996; Peterka, 2002).

On the other hand, visual stabilization of posture decreases when the distance to target fixation increases; this was initially attributed to decreased angular size of retinal slip induced by body sway (Bles et al., 1980; Paulus et al., 1984; Brandt et al., 1986; Paulus et al., 1989). Kapoula and Le (2006) showed that in addition to retinal slip, the ocular motor signals from the converging eyes, and perhaps related neck muscle activity, are involved in postural stabilization at a close distance. Le and Kapoula (2007) examined posture and vergence angle at several distances and suggested that at intermediate and far distances (i.e. beyond 90 cm) the central nervous system would use mostly internal signals (vestibular, proprioceptive, and somatosensory), while at close distance both visual and horizontal vergence oculomotor signals would be significant.

Vertical heterophoria (VH) is a relative deviation of the visual axes reduced via binocular vision mechanisms (Amos and Rutstein, 1987). VH exists in normal subjects, inferior to 1 diopter, on average $0.16 \pm 0.01°$ corresponding to 0.28 diopter (van Rijn et al., 1998).

Numerous patients without a precise anatomical diagnosis, without neuropathy or rheumatism, suffer from postural disorders and complaints such as chronic neck pain, low back pain, headache (e.g. Lápossy et al., 1995; Hagen et al., 2006), vertigo (e.g. Bucci et al., 2006; Treleaven et al., 2008) or proprioceptive impairment for instance at spine, ankle or knee levels (e.g. Morningstar et al., 2005; Treleaven, 2008). Clinical study of the management of chronic pain syndrome suggested an association with VH and balance problems that were clinically evaluated (Matheron et al., 2005). Indeed, Matheron et al. (2005) reported that in patients with chronic pain syndrome associated with VH, a specific proprioceptive physiotherapy acting on oropharynx, temporomandibular joint and/or pelvis most of the time restored vertical orthophoria (VO) immediately and diminished pain (evaluated with the

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subjective visual analog scale – VAS – introduced by Huskisson, 1974); moreover, such physical therapy improved mobility of spinal and peripheral joints, and normalized behavior in the balance tests. These clinical observations were corroborated by a laboratory study in which VH was artificially induced in healthy subjects by the insertion of a vertical prism; the prism modified postural stability (Matheron et al., 2007).

This study was designed to test the hypothesis that the quality of postural performance in quiet upright standing could be lower, even for normal healthy subjects with vertical heterophoria within the physiological range, than those with vertical orthophoria.

The results confirmed this expectation; moreover, an additional study showed that the cancellation of the small vertical heterophoria with a prism led to the improvement of postural stability.

2. Materials and methods

2.1. Subjects

Twenty-six healthy young subjects (15 females, 11 males) in the age range of 22–34 years (27.04 ± 3.29 years) were recruited among the laboratory co-workers, without neurological, otoneurological or ophthamological symptoms, with no medication or musculoskeletal problem. They all had normal vision with no history of strabismus, double vision, nor any other manifest ocular disease. The subjects with glasses were not included, as their glasses can already have some prismatic effects, and thus vertical eye deviation. We used the Maddox rod test which is appropriate for measuring clinically the vertical deviation or heterophoria (Daum, 1991; Wong et al., 2002; Casillas Casillas and Rosenfield, 2006). In normal young adults, when this test done in free space, it gives good repeatability in detecting small VH, inferior than 1 diopter while fixating at a far target (Casillas Casillas and Rosenfield, 2006). The cover test (alternative occlusion of one eye) may fail to detect VH in normal subjects; in contrast the Maddox Rod test succeeds measuring small VH similarly to the objective recording of eye alignment (e.g. by the magnetic search coil) (Wong et al., 2002). The Maddox Rod test was run as follows. The subject stood erect, 5 m in front of a point of light, in an anatomically referenced position. Maddox's rod, with its stripes running vertically, was placed in front of one eye, transforming this point into a red horizontal line; the other eye saw the point. The test was done on each eye (see von Noorden, 1996). The task consisted in positioning the light point on the red line; presence of vertical heterophoria was concluded when the line was over or under the point. The Maddox rod test was combined with the bar prism to measure the deviation of the eyes, i.e. to align the red horizontal line with the light (von Noorden, 1996). According to this test, 12 of the subjects recruited showed perfect orthophoria, i.e. perfect alignment of the eyes, and 14 subjects had small vertical heterophoria which was in the range of normal values, i.e. inferior to 1 diopter (see van Rijn et al., 1998), for one eye or both.

The investigation adhered to the tenets of the Declaration of Helsinki and was approved by the institutional human experimentation committee. Informed consent was obtained from all subjects after the nature of the procedure had been explained.

2.2. Platform characteristics

To measure postural stability, we used a force platform (principle of strain gauge) consisting of two dynamometric clogs (Standards by Association Française de Posturologie; produced by TechnoConcept, Céreste, France). Body sway was evaluated by computing the excursions of the center of pressure (CoP) measured over a period of 25.6 s; the equipment contained an Analog–Digital converter of 16 bits and the sampling frequency of the CoP was 40 Hz.

2.3. Visual target

A vertical screen was used to display a target along the vertical midline. The target was a letter "x" placed between two vertical segments. The angular size of the letter "x" was adjusted to subtend 1° for both viewing distances (200 and 40 cm). At 200 cm, the angle of vergence was 2° while at 40 cm it was 9°. The visual target was placed at eye level for each subject in upright stance on the force platform.

2.4. Testing conditions

Quiet stance posturography was carried out in an experimental room normally furnished. Subjects were placed on the force platform and were asked to fixate the "x" target in the straight ahead position. The target was placed at either 200 or 40 cm, at eye level (see Fig. 1). During posturography, subjects looked at the target that was clearly visible for both distance conditions. The order of the two distances was counterbalanced between subjects. For each distance, the recording was done twice. The subjects sat on a chair. We asked the subjects to close their eyes before standing up. Then, upon a "go" signal given by the investigator, the subjects opened their eyes at the moment the posturography recording started. A one-minute rest period was applied between any two conditions.

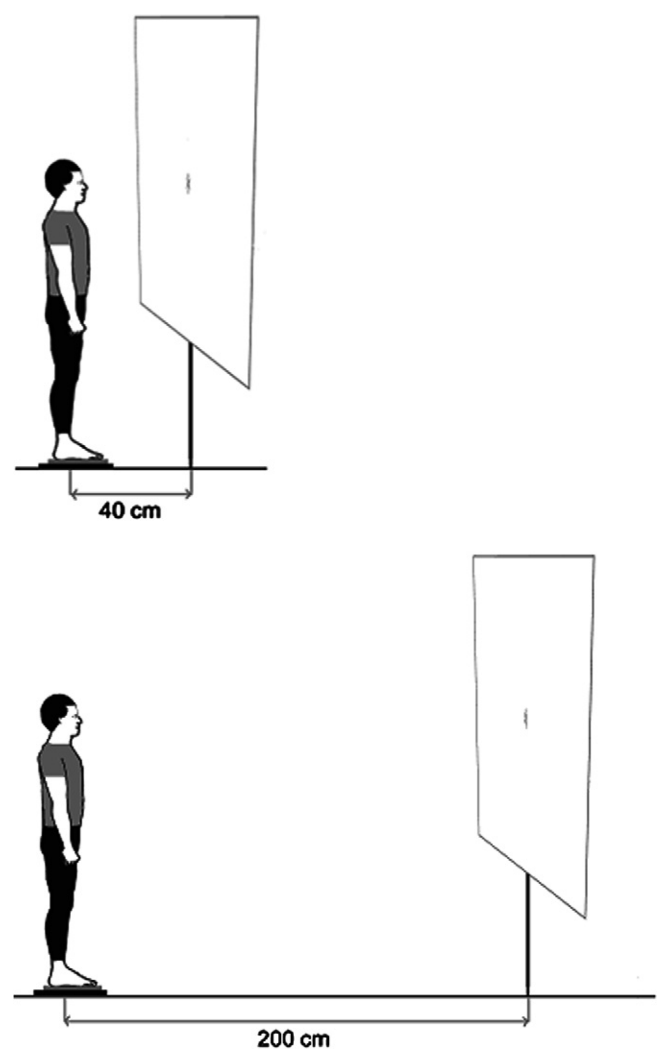

Fig. 1. Illustrations of posturography testing conditions. The subject viewed a cross target embedded by two vertical line segments that aimed to reinforce accurate fixation of the letter "x", at 40 and 200 cm.

2.5. Postural parameters

We analyzed the surface of the CoP excursions, the standard deviations of lateral (SDx) and anterio-posterior (SDy) body sways and the variance of speed. The surface area was measured with the confidence ellipse including 90% of the CoP positions sampled (Takagi et al., 1985; Gagey and Weber, 1999), eliminating the extreme points.

2.6. Additional experiment

Twelve new healthy young subjects (7 females, 5 males) in the age range of 17–32 years (22.25 ± 4.85 years) took part in this experiment using the same criteria as in the main experiment; they were recruited because they had a VH in physiological range.

In order to measure the small VH, the following procedure was used. First, the Maddox Rod test was carried out for either eye; a small prism (0.25, 0.50 or 0.75 diopter) was placed over the eye to cancel the VH. The value of the prism used corresponded to the value of the VH. Second, the prism was placed on either eye and we retained the final prism correction, the prism that eliminated vertical heterophoria when the Maddox Rod test was carried out on either eye (Fig. 2, Table 1).

Posturography was done while the subjects fixated the "x" target at 200 cm as in the main experiment. At the beginning of posturography, the subject wore a special spectacle frame and performed two conditions, each one twice (i) with the above-mentioned prism correction inserted on the spectacle frame, in front of the eye for which vertical orthophoria was obtained with the Maddox Rod test for either eye (ii) and without prism correction. The conditions were counterbalanced between subjects; the duration of each recording was 25.6 s.

2.7. Statistical analysis

For each distance, the data for the two recordings were average.

After the log transformation of the data, a mixed ANOVA design was used, with a main factor, the viewing distance with two levels (far and close), and one inter-subject factor, the vertical phoria with two levels (VO and VH). The post hoc comparisons were done by the Scheffé post hoc test.

For the additional experiment, the normality of the postural data distributions was tested using the Kolmogorov–Smirnov test. As distributions were normal, the paired t-test was performed to evaluate if there was a significant difference between the normal viewing condition and the prism condition for all the parameters of posturography; $p < 0.05$ was considered significant.

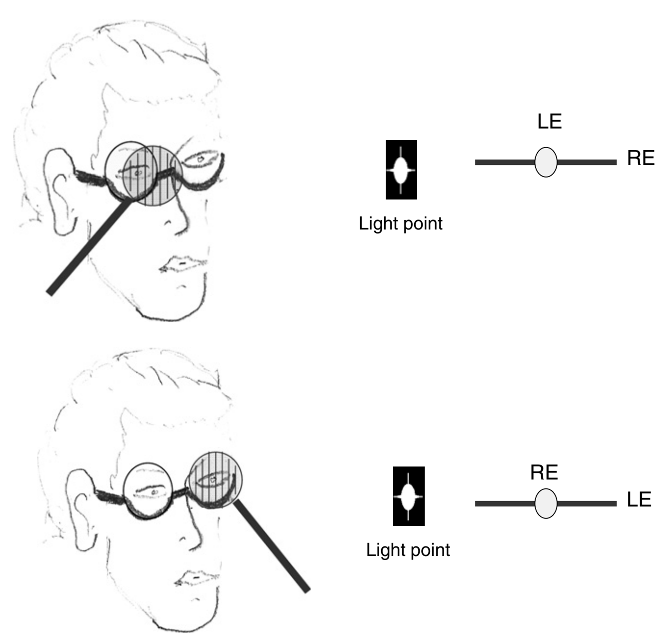

Fig. 2. The final prism correction, here on the right eye; the prism eliminates vertical heterophoria when the Maddox Rod test is done on the right (RE) and on the left eye (LE): the line is on the point of light.

Table 1
Detection and measurement of the vertical phoria for the right eye (RE) and the left eye (LE) using the Maddox Rod test in 12 subjects (complementary experiment)

Subjects	Vertical	Phoria	Prism correction (VO for both eyes)		
	RE	LE	Amount	Orientation	Eye
S1	VO	HR 0.25 Δ	0.25 Δ	BU	RE
S2	HP 0.5 Δ	HR 0.75 Δ	0.75 Δ	BU	RE
S3	HP 0.25 Δ	HR 0.50 Δ	0.25 Δ	BU	RE
S4	HP 0.75 Δ	VO	0.75 Δ	BU	RE
S5	VO	HR 0.50 Δ	0.50 Δ	BD	LE
S6	HP 0.25 Δ	VO	0.25 Δ	BU	RE
S7	HP 0.25 Δ	VO	0.25 Δ	BD	LE
S8	HR 0.25 Δ	VO	0.25 Δ	BD	LE
S9	VO	HR 0.25 Δ	0.50 Δ	BU	RE
S10	HR 0.25 Δ	HP 0.25 Δ	0.25 Δ	BU	LE
S11	HR 0.75 Δ	VO	0.50 Δ	BU	LE
S12	HR 0.25 Δ	VO	0.25 Δ	BU	LE

Vertical orthophoria (VO), hyperphoria (HR) and hypophoria (HP) which are vertical heterophoria (VH), respectively, upward and downward deviation; and their prismatic correction: the amount (in diopter), orientation of the vertical prism – base up (BU) or base down (BD) – and the eye that received it (RE or LE) for the subject viewing was VO on both the left and the right eye.

3. Results

3.1. Main experiment

For the main experiment, means and standard errors are shown in Table 2 for each group of subjects (VO and VH) and for each distance (close and far) for all postural parameters.

Next, we will present the results of ANOVA evaluating the effects of vertical phoria conditions and distance conditions on postural parameters, i.e. the surface area of the CoP excursions, the standard deviations of lateral (SDx) and anterio-posterior (SDy) body sways, and the variance of speed.

Table 2
Postural stability measurements in quiet stance (25.6 s duration) for 12 VO and 14 VH subjects

Parameters	Distance	
	40 cm	200 cm
Surface of CoP (mm^2)		
VO	59.5 ± 31.04	62.55 ± 31.14
VH	106.64 ± 49.58	165.09 ± 70.79
SDy (mm)		
VO	3.06 ± 1.02	3.11 ± 0.98
VH	3.80 ± 1.40	4.89 ± 1.43
SDx (mm)		
VO	2.03 ± 0.74	2.00 ± 0.92
VH	2.55 ± 0.87	3.30 ± 1.07
Variance of speed (mm^2/s^2)		
VO	21.37 ± 14.67	26.65 ± 16.60
VH	33.53 ± 5.16	38.97 ± 6.36

Means and standard deviations of surface of CoP, standard deviations of anterio-posterior (SDy) and of lateral body sway (SDx) and variance of speed for each distance (40 cm and 200 cm).

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3.1.1. Distance effect

There was a main effect of distance on all postural parameters tested in upright stance: the surface of the CoP ($F_{(1,24)} = 6.97$; $p = .014$), the standard deviations of lateral (SDx) body sways ($F_{(1,24)} = 5.15$; $p = .033$), the standard deviations of anterio-posterior (SDy) body sways ($F_{(1,24)} = 4.34$; $p = .048$) and the variance of speed ($F_{(1,24)} = 6.07$; $p = .021$). All parameters were significantly smaller at close distance than at far.

3.1.2. Vertical phoria effect

There was no main effect on the variance of speed ($F_{(1,24)} = 2.95$; $p > .05$) but a significant main vertical phoria effect on the surface of the CoP ($F_{(1,24)} = 21.40$; $p = .0001$), on the standard deviations of lateral (SDx) body sways ($F_{(1,24)} = 8.05$; $p = .009$) and on the standard deviations of anterio-posterior (SDy) body sways ($F_{(1,24)} = 10.36$; $p = .006$) where these parameters were significantly smaller in subjects with a vertical orthophoria than those with a vertical heterophoria (see Fig. 3a–d).

3.1.3. Interaction between the vertical phoria and the viewing distance

There was a significant interaction between the vertical phoria and the viewing distance for the surface of CoP ($F_{(1,24)} = 5.38$; $p = .029$), but not for the lateral (SDx) body sways ($F_{(1,24)} = 2.88$; $p > .05$), the standard deviations of anterio-posterior (SDy) body sways ($F_{(1,24)} = 3.14$; $p > .05$) nor for the variance of speed ($F_{(1,24)} = .27$; $p > .05$).

3.1.4. Local comparisons between distances

The Scheffé post hoc test showed that the surface of CoP was significantly smaller at near than at far viewing distance for the subjects with vertical heterophoria ($p = .013$, see Fig. 3a).

3.1.5. Local comparisons between the vertical phoria and the viewing distance

The Scheffé post hoc test showed a significant difference between the two groups of subjects' i.e. VO versus VH, at 40 cm and at 200 cm: the surface of CoP was significantly higher in subjects with vertical heterophoria (respectively, $p < .001$, $p < .000001$, see Fig. 3a).

To sum up, the results show main effects (i) of distance, i.e increasing of all parameters when the distance increases (ii) of vertical phoria, i.e. the subjects with vertical heterophoria are less stable. These subjects show a greater instability than those with vertical orthophoria when they are looking at a target at a far distance.

3.2. Additional experiment

Table 3 shows group mean values for each posturography parameter and for normal and prismatic viewing conditions. The *t*-test showed the following. The surface of CoP and the standard deviations of the anterio-posterior body sway were significantly smaller in the prism condition (respectively, $t = 3.53$, $p = .005$; $t = 3.20$, $p = .008$, see Fig. 4a and c). No difference was found between the normal viewing and the prism correction conditions for the standard deviations of the lateral body sway and the variance of speed (respectively, $t = 1.78$, $p = .103$; $t = 1.27$, $p = .232$, See Fig. 4b and d).

Table 3

Postural stability measurements in quiet stance (25.6 s duration) for 12 VH subjects

Parameters	200 cm
Surface of CoP (mm2)	
NV	136.79 ± 69.96
PC	89.86 ± 35.40
SDy (mm)	
NV	4.10 ± 1.41
PC	3.18 ± 0.81
SDx (mm)	
NV	2.76 ± 1.03
PC	2.33 ± 0.74
Variance of speed (mm^2/s^2)	
NV	53.12 ± 29.71
PC	43.56 ± 23.09

Means and standard deviations of surface of CoP, standard deviations of anterio-posterior (SDy) and of lateral body sway (SDx) and variance of speed for each distance in normal vision (NV) and in prism correction (PC) of VH conditions at 200 cm.

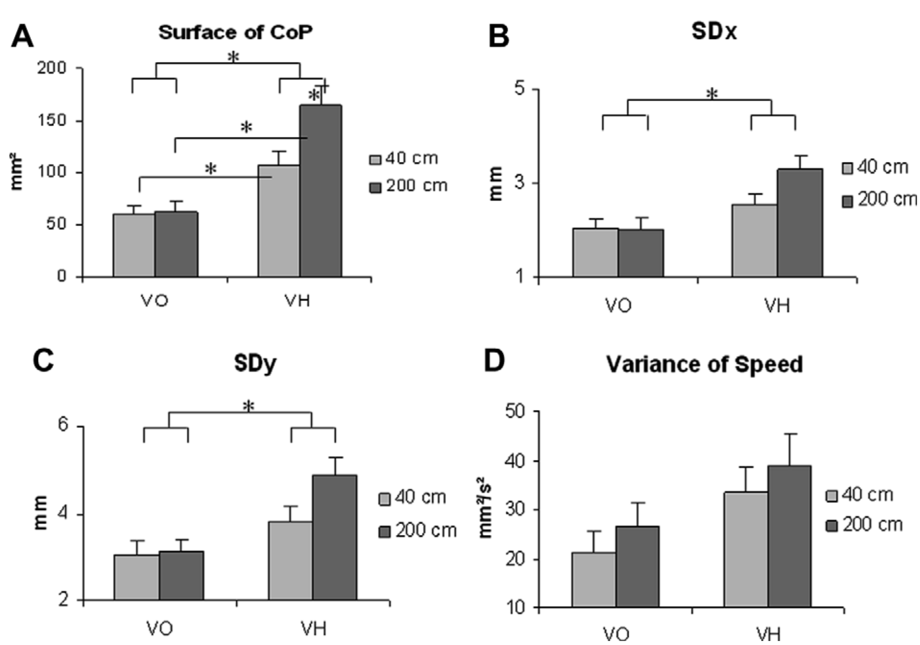

Fig. 3. Means of the surface area of CoP (mm^2) (A), the standard deviation of lateral (SDx) (B) and anterio-posterior (SDy) (C) body sways and the variance of speed (D) in VO and VH subjects for each distance (40 and 200 cm). Error bars represent the standard error.

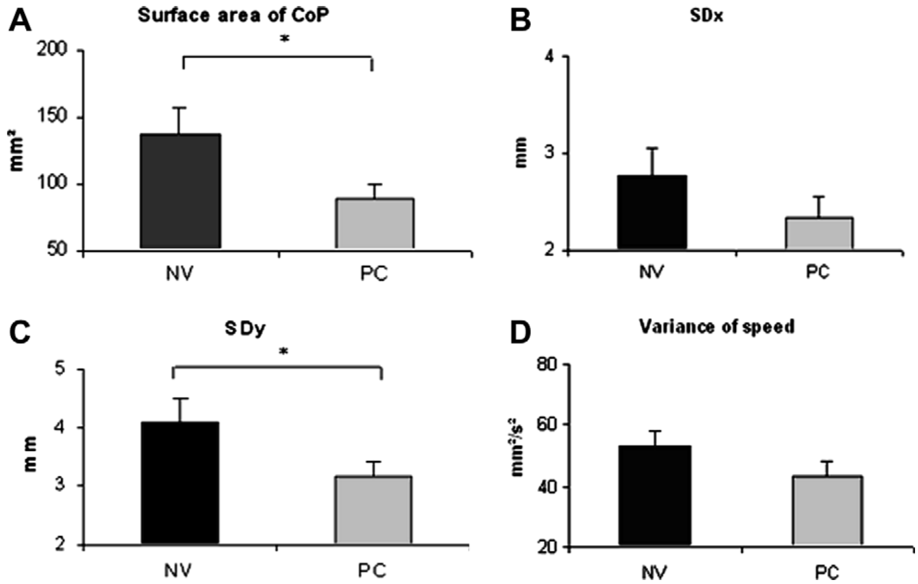

Fig. 4. Means of the surface area of CoP (mm^2) (A), the standard deviation of anterio-posterior (SDy) (B) and lateral (SDx) (C) body sways and the variance of speed (D) in VH subjects at 200 cm in normal viewing (NV) and in prismatic correction (PC). Error bars represent the standard error.

4. Discussion

4.1. Subjects with physiological vertical heterophoria are less stable

The most important finding is that healthy young adults with a small VH within the physiological range, i.e. less than 1 diopter (0.57°), showed greater postural instability than the subjects with VO. The link between vertical phoria and posture was confirmed by the additional experiment in which the cancellation of the VH by an appropriate prism improved postural stability. VH contributes to the variability of postural performances among healthy subjects. Indeed, variability has been reported by others.

Lacour et al. (1997) studied postural control recording at 1.2 m and found that some normal subjects used preferentially visual cues to stabilize their body oscillations in quiet stance while others used preferentially somatosensory/proprioceptive cues. Le and Kapoula (2007) suggested that from 90 cm and beyond, the central nervous system uses more vestibular, proprioceptive and somatosensory information than the vision and vergence oculomotor signals. Thus, distance is another important factor influencing the normal performances. Our results in line with the state of vertical phoria shed light on another factor contributing to normal variability.

4.2. Influence of vertical heterophoria on posture stability: hypothetical mechanisms

Next, we will summarize neuroanatomic studies showing a structure within which eye alignment signals could influence posture.

The gaze signals influence both the vestibulospinal and reticulospinal systems (Berthoz, 1988). The vestibulospinal tract receives otolith input and afference from the cerebellum, exerts excitatory effects on extensor motoneurons and inhibitory on flexor motoneurons during postural control. The reticulospinal tract receives input from vestibular organ, controls general muscle tonus and has a role in postural adjustment. The tectospinal and the interstitiospinal tracts originate, respectively, from the superior colliculus and the nucleus of Cajal, receive visual inputs, and are involved in the control of eye and head coordination, and can influence the reticulospinal system which contributes to postural control (Shinoda et al., 2006). The superior colliculus receives in addition to direct retinal inputs, somatosensory inputs, signals from the basal ganglia and cerebellum, and is connected with brainstem, spinal cord and medullary reticular formation regions (May, 2006). Next, we will focus on the role of cerebellum for both phoria adjustment and postural control.

Cerebellar neuronal circuits play a direct role in both controlling eye movements (Sunartpin and Kotchabhakdi, 2005) and keeping the centre of gravity within the limits required for a stable upright standing (Diener et al., 1989). The cerebellar vermis and the visual cortex are activated during upright standing in binocular viewing; the activation of the visual cortical fields can subserve stereopsis and motion vision to maintain posture stability (Ouchi et al., 1999). Particularly there is evidence that vertical phoria is under adaptive control of the cerebellum. Kono et al. (2002) studied vertical phoria adaptation (using vertical prism) in patients with inflammatory syndrome of cerebellar dysfunction; phoria adaptation was found to improve with remission of this cerebellar inflammatory syndrome. We suggest that the residual VH seen in normal subjects reflects some limitations of the normal cerebellar adaptive mechanism controlling the vertical binocular eye alignment. The residual vertical eye misalignment would influence the quality of postural stabilisation as the cerebellum receives both visual and proprioceptive signals, and controls postural stability. The importance of vertical eye misalignment on posture has also been shown in the study of Matheron et al. (2007), in which experimentally induced VH by a prism modified postural stability as the prism acted on extraocular proprioception. Proprioceptive signals from extraocular muscles are important in the development and maintenance of normal binocular function, in spatial localization (Weir et al., 2000), in calibration and sensory perception of eye position (Wang et al., 2007), and are used to adapt adjustment of binocular alignment (Büttner-Ennever, 2006).

4.3. Postural instability at far occurs for subjects with VH

Postural stability in our study decreased as the distance increased. This confirmatory finding was attributed to joint action of decreasing with viewing distance of the weight of retinal slip inputs (Bles et al., 1980; Paulus et al., 1984; Brandt et al., 1986; Paulus et al., 1989) and of the ocular motor convergence signals

(Kapoula and Le, 2006). Interestingly, the deterioration of posture stability at far distance was essentially present for the subjects with VH. Inspection of individual data indicated that postural stability decreased with distance in 12 of the 14 VH subjects; on average, the surface area of the CoP excursion increased by 79 mm^2 for these subjects. In contrast, in the presence of VO, the postural stability decreased with distance in only 7 of the 12 subjects, and by a smaller amount (18 mm^2 for the surface area). The decrease was not significant.

We speculate that the difference observed between the two groups in the performance of postural stability in far viewing distance could be due to difference in their capability to use proprioceptive cues to stabilize posture. In line with a study of Le and Kapoula (2007), we suggest that the use of proprioceptive information might be more important for far distances, and that subjects with VH reveal instability because of their reduced capacity for vertical vergence at far distance, having residual vertical eye misalignment. Indeed, Casillas Casillas and Rosenfield (2006) found that VH could be present in normal subjects in far distance but not in close distance. Vertical fusional responses to disparities are better at near distance than at far distance (Steffen et al., 2000); they are strongly correlated to the vergence angle and could compensate VH at near vision (Bharadwaj et al., 2007). On the other hand, distance dependency of oculomotor response to vertical disparity could be related to sensory processing of disparity. The activity of binocular disparity neurons in area V1 is also distance modulated due to extraretinal signals, probably proprioceptive (Trotter et al., 1996).

The additional experiment showed that a small vertical prism could nullify VH, modifying extraocular proprioceptive cues and thereby improving postural stability. Our data are in line with other studies showing the importance of proprioception in general. For instance, Roll and Roll (1988) showed that for a subject in upright stance looking at a small target in darkness, the vibrations applied to the extraocular lateral rectus, to the trapezius or to the peroneus lateralis elicited an illusory target displacement in the lateral direction, as in the case of masseter and temporalis muscles (Matheron et al., 2004). Applying vibratory stimulations to masseter and temporalis muscles elicited such visual displacement in the vertical plane in subjects with VH, but not in subjects with VO, suggesting that these muscles were part of the lateral muscle proprioceptive chain and that proprioceptive dysfunction could interact on the anterio-posterior chain (Matheron et al., 2004).

4.4. Clinical aspects

Our results are in line with previous clinical study showing better performance in balance control for subjects with chronic pain (spine and/or joint pain) and VH after restoration of VO (Matheron et al., 2005). Indeed, it was reported that when VH at far vision was qualitatively detected with Maddox's rod, proprioceptive maneuvers applied to oropharynx, temporomandibular joint and/or pelvis immediately restored VO (for 90% of these subjects) and reduced pain. Postural instability was found in several functional disorders including vertigo without vestibular finding (Bucci et al., 2006; Treleaven et al., 2008), dyslexia (Pozzo et al., 2006; Kapoula and Bucci, 2007), chronic pain (e.g. Lápossy et al., 1995; Hagen et al., 2006) and fibromyalgia (McCabe et al., 2007). To our knowledge, phoria, particularly vertical phoria has not been characterized yet in such functional disorders and would be of interest. Indeed, one can think that somatosensory/proprioceptive conflict can lead to these postural instabilities; this is supported by the study of McCabe et al. (2007) who introduced an experimental model providing evidence that sensory-motor conflict could exacerbate pain and modify sensory perception, even in the absence of injury. Studies of patients with chronic pain syndrome and VH are in progress in our laboratory.

In conclusion, the results, in which subjects with small VH even within the normal range are less stable than those with VO, could be attributed to a somatosensory/proprioceptive difference in the sensorymotor loop controlling balance posture in upright stance via the afferences and efferences from the cerebellum and its role of calibration. Outside neurological or ocular disease, we speculate that vertical phoria could be the sign of the capacity of the central nervous system to integrate optimally proprioceptive cues. Using the Maddox rod test in this way, i.e to determine the vertical phoria state, prevention possibilities could be investigated.

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