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ORIGINAL ARTICLE

Effect of vision, proprioception, and the position of the vestibular organ on postural sway

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Abstract

Conclusion: When measured together, it seems that vision and proprioception as well as position of the vestibular organ affect postural sway, vision the most. Mediolateral (ML) sway does not seem to be influenced by the position of the vestibular organ. *Objective:* To investigate how postural sway was affected by provocation of vision, by the position of the vestibular organ, and by provocation of proprioception, when measured together. *Methods:* Postural sway was measured by using a force plate. Tests were performed with eyes open and eyes closed, with head in neutral position and rotated to the right and to the left and with head maximally extended, both standing on firm surface and on foam. Measures of ML speed (mm/s), anteriorposterior (AP) speed (mm/s), and sway area (SA) (mm^2/s) were analyzed using a multilevel approach. *Results:* The multilevel analysis revealed how postural sway was significantly affected by closed eyes and standing on foam, and by the position of the vestibular organ. Closed eyes and standing on foam both significantly prolonged the dependent measurement, irrespective of whether it was ML, AP or SA. However, only AP and SA were significantly affected by vestibular position, i.e. maximal head movement to the right and extension of the head.

Keywords: *Postural control, balance, vestibular system*

Introduction

Satisfactory balance is necessary for most everyday activities [1]. Balance, postural control or equilibrium are definitions used to describe how we keep our body in an upright position and, when necessary, adjust this position. It has been described as ‘sensing the position of the body’s centre of mass and moving the body to adjust the position of the centre of mass over the base of support provided by the feet’ [2]. To maintain balance, vision, the somato-sensory system, and the vestibular organ interact and register inputs from the surroundings, which are integrated and processed in the central nervous system. The vestibulo-ocular reflex (VOR) coordinates eye and head movements, making it possible, for example, to walk and read signs at the same time [3]. The cervico-ocular reflex interacts with the VOR, providing information about head movements in relation to the trunk [4]. Sensory receptors in the skin as well as mechanoreceptors in the muscles provide input as to how gravity affects the body [5,6]. For the preservation of balance, input from the different parts of the balance system is constantly reconsidered and response from the motor cortex is sent back. This means that the body is constantly in motion, which is called postural sway [1].

Balance is often measured by using a force plate and measuring the movement of the centre of pressure (COP) in the mediolateral (ML) direction as well as in the anteriorposterior (AP) direction [1,7]. Force plate measures can also be used as a predictive value for falls [8].

Postural sway has been shown to increase when eyes are closed [7] and during visual stimulation [9].

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Performing head movements, holding the head in extended tilt position, and disturbance in cervical proprioception can also increase postural sway [10,11]. Also, decrease in pressor information from the feet has been shown to increase lateral body sway [5] and postural sway increases when a person is standing on foam [12]. However, it seems that the way in which vision, proprioception, and the position of the head affect postural sway when measured together is not yet fully understood.

Therefore the aim of this study was to investigate how postural sway was affected in tests with eyes open and eyes closed, in tests with the head in different positions, and in tests when standing on a firm surface as well as on foam, and when these measures were performed together.

Material and methods

Subjects

There were 30 subjects in the study, 25 women and 5 men, all healthy adults between the ages of 21 and 59 (SD 12 years). They were 156–198 cm (SD 9.8 cm) tall. All subjects had normal range of motion in the neck, had normal vestibular function, and had no problems with dizziness, pain or decreased range of motion in the lower extremities. All had normal vision, some of them after correction with glasses or lenses.

Equipment

Postural sway was measured in a standard treatment room, using a triangular force plate, with strain gauge transducers at each corner of the platform, and the program installed in a laptop PC (Good Balance™, Metitur Ltd, Finland, www.metitur.com). On the basis of the vertical force signals from each corner of the platform, the system calculated the mean speed of the movement of center of pressure (CO) in the ML direction as well as in the AP direction (mm/s). Sway area (SA) (mm^2/s) was also measured. The system corrects for differences in body height as described by Era et al. [7]. Force plates have been tested for test–retest and intrasession reliability as well as validity [7,13].

Procedure

The starting position on the force plate was normal standing with arms in front, one hand grasping the wrist of the other arm, feet in standardized position with toes 30° rotated outwards. The subjects were told to hold their head in neutral position and to stand as still as possible. Sixteen different measures were performed for 30 s each time. Tests were performed both with eyes open and with eyes closed, with head held in neutral position, with head maximally rotated first to the right, then to the left, and thirdly, with head maximally extended backwards. Tests were also performed on a firm surface and when the subject was standing on 3 cm thick foam, which was shaped in the same way as the force plate. The tests were performed in the order presented in Table I.

Statistics

Considering standard deviation (SD) for measures on the force plate [7], a power of 80% and the significance level set at 0.05, a sample size of 30 subjects was required [14].

Because the observations are repeated measures within the same subject, there is dependence between measurements. To correct for this deviation from the prerequisites for a traditional regression model, we used a multilevel approach, where a correction for dependence is built into the model [15,16]. We regarded the repeated measures as clustered within the subjects, thus giving a two-level structure. The dependent variables used were ML, AP, and SA. The independent variables used were vision (eyes open or closed), position of vestibular organ (head in neutral position, head maximally rotated to the right, head maximally rotated to the left, and head maximally extended), and surface (firm surface and foam). Each dependent variable (ML, AP, SA) was analyzed separately with all independent variables.

We began the multilevel analysis with a so-called empty model, i.e. a model with a fixed part and a random part. The fixed part models the effect of the mean that underlies all observations. The random part consists of a decomposition of the total variance into two levels: variance between subjects (second level) and between occasions within subjects.

The empty model is then extended by including the independent variables in the fixed part of the model. Inclusion was made stepwise, but only the last model with all variables is presented.

Analysis was done with MlWin, v 2.17 [17]. Residual (or restricted) maximum likelihood (REML) was used for all analysis. REML estimation takes into account the loss of degrees of freedom resulting from the estimation of the parameters of the fixed part. This has an indirect effect on the estimates of the fixed part.

The results are presented with 95% confidence intervals (CIs) [18].

Table I. Mean values and standard deviation (SD) for mediolateral (ML) sway, anterior-posterior sway (AP), and sway area (SA) under the various conditions.

Parameter	Test	ML speed (mm/s)	AP speed (mm/s)	SA (mm^2/s)
Vision	NEo	3.7 (1.5)	4.7 (1.4)	8.4 (4.3)
	NEc	5.7 (3)	8.7 (3.2)	18.0 (12.6)
Vision and position of vestibular organ	RoREo	4.3 (2.3)	6.5 (1.8)	12.8 (8.7)
	RoLEo	3.7 (1.4)	5.7 (1.4)	11.2 (5.2)
	RoREc	5.6 (2.7)	9.0 (3.1)	19.5 (12.9)
	RoLEc	5.4 (2.9)	8.8 (2.3)	19.4 (12.3)
	ExEo	4.4 (1.6)	8 (2.4)	15.0 (6.9)
	ExEc	5.6 (2.8)	10.1 (3.1)	22.2 (13.3)
Vision, position of vestibular organ, and proprioception	FNEo	4.7 (1.6)	6.7 (1.7)	15.5 (7.8)
	FNEc	8.8 (3.5)	13.7 (2.6)	41.2 (19.2)
	FRoREo	5.3 (1.6)	8.8 (2.1)	22.9 (13.4)
	FRoLEo	4.6 (1.4)	7.6 (1.8)	16.7 (7.5)
	FRoREc	8.1 (3.2)	15.1 (4.7)	44.8 (26.0)
	FRoLEc	7.8 (4.5)	13.9 (4.5)	40.9 (29.1)
	FExEo	5.4 (1.4)	10.9 (2.9)	28.6 (13.9)
	FExEc	9.1 (3.7)	17.2 (5.2)	57.6 (28.6)

N, neutral head position; Eo, eyes open; Ec, eyes closed; Ro, rotation of the head; R, to the right; L, to the left; Ex, extended neck; F, foam.

A reduction in the total variance is an indicator of a better ‘fit’ of the model, as is the reduction in the deviance.

Ethics

All subjects participated voluntarily and consent was obtained before the tests were carried out. The measures were performed according to guidelines set out by the Helsinki Declaration of 1974. According to Swedish law, no approval from an ethical review board was therefore necessary.

Results

Standing with eyes open on a firm surface caused the smallest postural sway in all dimensions, and standing with head extended and eyes closed on foam differed the most from standing with eyes open on a firm surface (Figure 1). Mean values and SD for each test are displayed in Table I.

Multilevel analysis – descriptive

The sway in AP was 50% higher than the sway in ML. However, both measures showed similar variations when the independent variables were measured. The total sway area was a different measure to AP and ML, but showed an analogous pattern.

Multilevel analysis – results

The empty model revealed a similar pattern for all outcomes, i.e. both random variance components (between subjects (second level) and between occasions within subjects) differed from zero. This warranted the use of a multilevel model.

Similarly, the introduction of independent variables revealed an almost uniform pattern: closed eyes and standing on foam both prolonged the dependent measurement, irrespective of whether it was ML, AP or SA. However, only AP and SA were affected by the position of the vestibular organ, i.e. maximal head movement to the right and extension. CIs for the independent variables as well as deviance are displayed in Table II.

Discussion

In this study, vision seemed to affect postural sway most, in terms of increased ML and AP sway as well as sway area. Proprioception also affected postural sway, in ML and AP sway, somewhat less than vision but in

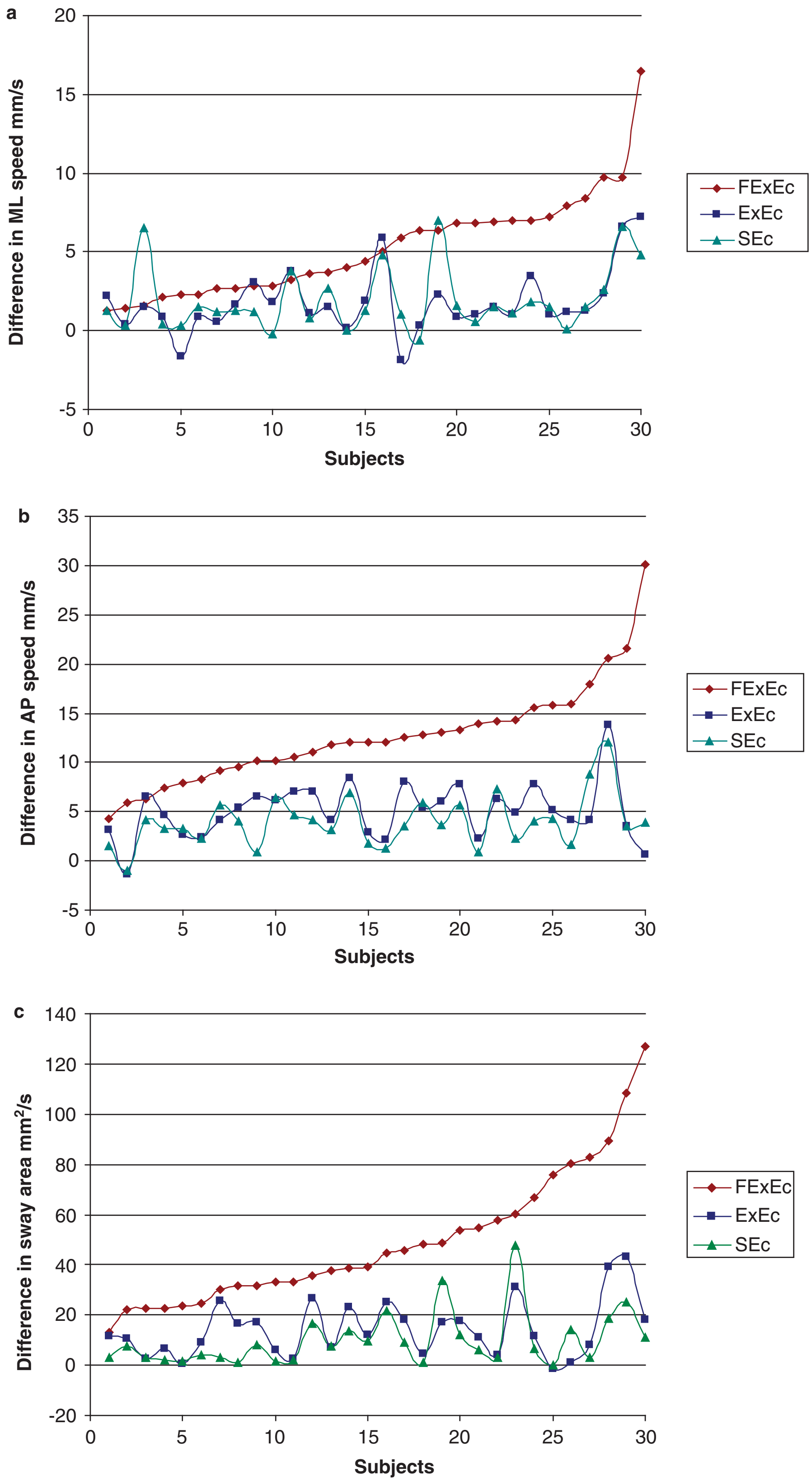

Figure 1. Bland–Altman plots showing the difference in mediolateral sway (a), anteriorposterior sway (b), and sway area (c) between normal standing, eyes open on firm surface (the zero-plot), and standing with eyes closed (SEc), standing with head extended and closed eyes (ExEc), as well as standing on foam with head extended and eyes closed (FExEc).

Table II. Results of multilevel analysis.

	ML speed		AP speed		SA	
Parameter	Empty model	Full model	Empty model	Full model	Empty model	Full model
Fixed part						
Intercept	5.77 (5.07–6.47)	3.54 (2.74–4.35)	9.74 (9.01–10.47)	4.12 (3.23–5.01)	24.70 (21.33–28.07)	3.65 (–0.79–8.08)
Vision		**2.47 (2.15–2.82)**		**4.70 (4.24–5.15)**		**16.57 (13.99–19.15)**
Position of vestibular organ						
RR		0.12 (–0.37–0.62)		**1.40 (0.75–2.04)**		**4.22 (0.57–7.87)**
RL		–0.36 (–0.85–0.14)		0.54 (–0.11–1.19)		1.27 (–2.38–4.92)
Ex		0.37 (–0.12–0.86)		**3.10 (2.45–3.74)**		**10.12 (6.46–13.76)**
Foam		**1.92 (1.57–2.27)**		**4.02 (3.57–4.48)**		**17.74 (15.16–20.32)**
Random parts						
Variance						
Within subjects (1 level)	6.29 (5.45–7.13)	3.65 (3.16–4.14)	17.95 (15.56–20.35)	6.29 (5.45–7.13)	370.7 (321.3–420.1)	199.6 (172.9–226.3)
Between subjects (2 level)	3.42 (1.40–5.23)	3.48 (1.57–5.40)	2.88 (0.81–4.95)	3.61 (1.54–5.57)	62.22 (18.05–106.39)	72.92 (28.79–117.04)
Deviance	2311	2061	2786	2314	4239	3956

Values are shown as means and 95% confidence intervals (CIs). Significant differences are displayed in bold type. ML, mediolateral sway; AP, anterior-posterior sway; SA, sway area. RR, rotation right; RL, rotation left; Ex, extension.

sway area somewhat more. The position of the vestibular organ, especially rotation of the head, seemed to have a smaller influence on postural sway, especially ML, than vision and proprioception.

Earlier studies have shown that males tend to have more pronounced sway [7]. Since there were only five men in our study group, we were not able to perform any analysis of difference between genders.

Each subject performed the tests in the same order. Since mean values differed so much between tests with eyes open and tests with eyes closed, and since mean values did not differ so much between tests with head rotated to either the left or right, we do not think that this affected the results. However, in future studies, the possibility of performing the tests in random order might be considered.

Power calculation was performed for calculating differences between the tests with *t* test. However, we believe that the power calculation is valid for multilevel analysis too.

There were no significant differences in ML for rotating the head to the right, to the left or extending the head, but significant differences in AP and SA for rotating the head to the right or extending the head, but not when rotating to the left. The test with rotation of the head to the right was performed first and the test with the head rotated to the left after. It is possible that adaptation to the movement occurred, which might explain the difference. Also, it is possible that ML was affected the least by rotation of the head, since the movement is tangential to the same movement as ML.

Means and SD for ML sway, AP sway and SA when standing with eyes open and standing with eyes closed in our study were similar to those found in a large population study from Finland [7].

Other studies have also confirmed vision as an important part of postural control [19,20]. Additionally, vision is more important to postural control when the proprioceptive information is reduced [21], and it is known that older people have to rely more on visual information to maintain balance [22]. Lateral control of posture has been shown to be important for predicting falls [8]. In our study ML postural sway was most affected by vision and by standing on foam, but not so much by the position of the vestibular organ. Similar findings to those in our study about the minor influence the position of the head has on postural control were reported in a study from 2006 [23]. Also, a study from 2000 has the same findings as ours, as regards the head-extended posture to increase postural sway [24]. Since vision is an important part of postural control, it seems important to consider vision when constructing vestibular rehabilitation programs, by using exercises with closed eyes in order to stimulate the other components in postural control and by using exercises that stimulate visiomotor coordination, especially for elderly persons or persons with impaired proprioception. Also, it seems possible to challenge the balance system even more by putting together the different ways of provoking postural control, as shown in our study.

Conclusion

When measured together it seems that vision and proprioception as well as the position of the vestibular organ affect postural sway, vision the most. The position of the vestibular organ seems to affect postural sway the least. ML sway does not seem to be influenced by the position of the vestibular organ. It seems important to consider vision when constructing vestibular rehabilitation programs, and also to challenge the balance system even more by putting together the different ways of provoking postural control.

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