The effect of vision elimination during quiet stance tasks with different feet positions

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Literature conﬁrms the effects of vision and stance on body sway and indicates possible interactions between the two. However, no attempts have been made to systematically compare the effect of vision on the different types of stance which are frequently used in clinical and research practice. The biomechanical changes that occur after changing shape and size of the support surface suggest possible sensory re-weighting might take place. The purpose of this study was to assess the effect of vision on body sway in relation to different stance configurations and width. Thirty-eight volunteers performed four quiet stance conﬁgurations (parallel, semi-tandem, tandem and single leg), repeating them with open and closed eyes. Traditional parameters, recurrence quantiﬁcation analysis and sample entropy were analyzed from the CoP trajectory signal. Traditional and recurrence quantiﬁcation analysis parameters were affected by vision removal and stance type. Exceptions were frequency of oscillation, entropy and trapping time. The most prominent effect of vision elimination on traditional parameters was observed for narrower stances. A signiﬁcant interaction effect between vision removal and stance type was present for most of the parameters observed (p < 0.05). The interaction effect between medio-lateral and antero-posterior traditional parameters differed in linearity between stances. The results conﬁrm the effect of vision removal on the body sway. However, for the medio-lateral traditional parameters, the effects did not increase linearly with the change in width and stance type. This suggests that removal of vision could be more effectively compensated by other sensory systems in semi-tandem stance, tandem and single legged stance.

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1. Introduction

Static balance tests (i.e. quiet stance tasks) are often used as part of functional assessment in elderly, athletes and other clinical populations [1–3]. Cross-sectional studies have shown that body sway parameters differ between young and elderly adults [4], as well as between healthy and health-deﬁcient individuals [5]. Furthermore, these tests have shown predictive power for falls in the elderly [6], detection of pre- and post-injury changes [7] as well as adaptations to long-term exercise [8].

Quality of balance control has been shown to be dependent on sensory input. Proper sensory input enables accurate anticipation of body sway and preparation of corrective anticipatory postural adjustments [9]. Various sensory ﬁelds (i.e. plantar, joint and muscle proprioceptors as well as vestibular and ocular organs) give speciﬁc information on the position and movement of the body in space. Vision has been shown to effectively compensate for the loss of other sensory ﬁelds [10,11]. In general, it has been suggested that removal of vision on its own increases body sway by more than one third in healthy young adults [12,13]. Moreover, narrower stances (comparing parallel and single leg stance) have been shown to be affected greater by vision removal than wider stances [14,15]. Interestingly, this effect was more pronounced in younger than in elderly subjects [15]. Most noticeable changes were observed in the centre of pressure (CoP) area [16] and path [17], although no changes were reported in the median frequency [17,18].

Reports on how the effect of vision is dependent on stance type (i.e. different shape and width of feet placement) are limited. This question is relevant from a clinical as well as from a research perspective. Changing conﬁguration and width of stance affects biomechanical characteristics of the human body, possibly affecting the sensory input from muscles and joints [18,19] and consequently body sway. Clinicians use different types of stance
configurations to modify sensitivity of a balance test according to age, injury or disease, regardless of possible differences in sensory re-weighting. Moreover, the research literature is usually limited to a small number of parameters, some of which have low reliability. The aim of this study was to assess the effect of vision on body sway by comparing stances of different configuration and width. We hypothesized that the effect of vision removal on body sway would increase linearly from wider towards narrower stance types, as suggested in the literature. Only parameters which proved as the most reliable in our previous research were used (data submitted for publication).

2. Methods

Thirty-six healthy volunteers participated in the study (24 men, 14 women; age (mean ± standard deviation) 27.6 ± 6.0 years; body height 176.6 ± 6.7 cm; body mass 70.4 ± 11.7 kg). Neurological, locomotor, vestibular and visual system disorders were used as exclusion criteria. Prior to their participation, each subject was informed about the course of the study and was required to sign an informed consent form approved by the national committee for medical ethics.

Prior to the measurement protocol each subject performed a stepping exercise for 4 min, stretching of the lower limb muscles and ten squats. Following the warm-up, subjects were required to perform a set of quiet stance balance tasks. Overall, stance in four different foot positions were carried out. In a parallel stance (PS) feet were placed at hip width (distance between fifth-metatarso-phalangeal joints 33.5 ± 1.7 cm, foot length 26.3 ± 1.2 cm). In a semi-tandem stance (STS) the dominant foot was placed forward. The first-metatarso-phalangeal joint of the dominant foot, touching the middle of the medial longitudinal arch of the dominant foot (stance length 33.1 ± 2 cm, lateral maximal width 19.9 ± 4.6 cm). In the tandem stance (TS) the dominant (forward) and non-dominant (backward) foot were positioned in a straight line, toes touching the heel (heel-toe length 52.1 ± 2.3 cm). During single-leg stance (SLS) the participants stood on their dominant leg. Each task was performed once with eyes opened (EO) and again with eyes closed (EC). The four stance types were repeated in a randomized order [20], each performed three times for 60 s. Three-minute breaks between the consecutive trials were used to avoid fatigue. When performing the quiet stance tasks with EO, the subjects were instructed to focus on a reference point marked on the wall at eye-height, 1.5 m in front of the participant and to stand as still as possible. In the EC variations of the task, a non-transparent band was placed over the head of the subject to completely cover their eyes. Throughout the measurement, their hands were placed on their hips, while keeping the knees fully extended (but not hyperextended). All of the participants were able to perform the given balance tasks except two who were unable to perform SLS-EC. Subsequently they were excluded from further analysis.

Displacement of the CoP was measured using a force platform (HEINE00600-2K AMTI, Watertown, USA) with a 1000 Hz sampling rate. Signals were stored on a personal computer for further analysis. The CoP signal was filtered (2nd order Butterworth, 0.1–20 Hz band-pass filter) and quantified with custom-written software (LabView, 8.1; NI, TX, USA). The following traditional parameters were calculated: the total (i.e. based on Euclidian distance) average CoP velocity (velocity); total average velocity in anterior–posterior and medial–lateral directions (velocity in a–p and m–l direction), total CoP displacement in anterior–posterior and medial–lateral directions (amplitude in a–p and m–l direction), and the average frequencies of CoP direction changes in anterior–posterior and medial–lateral directions (frequency in a–p and m–l direction). Further, recurrence quantification analysis (RQA) was performed [21]. This analysis is based on a nonlinear, multidimensional technique which does not assume the data is stationary and provides description of various features in a given time series, including quantification of deterministc structure and non-stationarity [22]. Finally, sample entropy data was obtained. Sample entropy provides information regarding the regularity and predictability of a time-series (CoP path) and it is used to analyze complex stochastic systems [23,24]. All the parameters were calculated as an average value of the 60-s trial. For each of the parameters the difference between the EO and EC was calculated and expressed as percentage.

Statistical analyses were performed using SPSS 13 (SPSS Inc., Chicago, USA). A three-repetition average of an individual parameter was calculated for each of the quiet stance tasks and taken for further statistical analysis. Effects of vision and stance were tested by two-way ANOVA. Effects of each variable (vision or stance) on individual parameters as well as their interaction effect were tested using RANOVA. Differences between vision conditions in each stance were tested with a post hoc t-test. An alpha error of 5% was used to consider the difference between stances and conditions as statistically significant.

3. Results

The two-way ANOVA showed general and significant effects of stance type ($F = 6.1–273.6$, $p = 0.000–0.001$) and vision ($F = 0.0–401.9$, $p = 0.000–0.015$) on most of the body sway parameters observed. The effect of vision was not significant for frequency, trapping time and entropy in the m–l direction ($F = 0.0–2.3$, $p = 0.136–0.886$). The manipulation of feet position resulted in statistically significant changes in the majority of the selected body sway parameters, both for EO ($F = 3.4–148.6$, $p = 0.000–0.020$) and EC ($F = 3.8–222.5$, $p = 0.000–0.012$). Table 1). The exception was trapping time in the m–l direction, on which vision had no effect ($F = 2.4$, $p = 0.066$). An interaction effect between vision and stance was statistically significant for all parameters observed ($F = 2.34–109.2$, $p = 0.000–0.060$), exceptions being frequency in the m–l and sample entropy in the m–l as well as in the a–p direction. The number of parameters which were sensitive to vision elimination increased in narrower stances. The parameters less affected by vision removal were frequency, sample entropy and trapping time in both m–l and a–p directions.

The increase in the traditional parameters after removing vision was most prominent for narrower stances (21–31% for PS and 113–135% for SLS). This increase was linear from PS to SLS for a–p traditional parameters, but not for m–l parameters. The highest increase in m–l parameters was observed from PS (21%) to STS (104–109%), but remained relatively constant in STS, TS and SLS (changing 2–10%, 104%, 117–118% respectively). RQA parameters were affected to a lesser extent by vision removal (differences in EO and EC ranged from –11% to 10% in STS, TS and SLS except for the recurrence rate. The recurrence rate in a–p direction increased linearly from PS to TS (~7%, 20–51%) and fell from TS to SLS (from 51% to 43%). A comparable trend was observed for recurrence rate in m–l direction, the only difference being in the TS (difference in EO and EC ~1%).

4. Discussion

This study showed that vision elimination significantly affects body sway, especially in narrower stances. However, not all CoP parameters representing body sway were changed in the same manner. The most prominent changes were observed in the amplitude and amplitude derived characteristics of the CoP (i.e. the majority of the traditional parameters such as amplitude and velocity). Conversely, speed of reactive control of body sway showed no sensitivity to vision removal (i.e. frequency, sample entropy and trapping time). Another important finding of this study was the significant interaction effect between vision elimination and stance type on body sway parameters measured. The interaction proved linear only for traditional parameters in the m–l direction. The nonlinearity of the interaction effect for the velocity in m–l direction, amplitude and RQA parameters suggests that sensory re-weighting took place after narrowing and changing shape of the support surface. From the perspective of clinical or rehabilitation practice, this study suggests that balance controlling mechanisms do not change the speed of reactive control after removing vision. Additionally, the stance used could alter the sensory input used in balance control, resulting in sensory re-weighting.

Traditional parameters have been proven sensitive to vision removal, especially in stances with narrower and an altered shape of the support base [14,15,25]. However, these studies compared only stances with significantly different width and shape of the support base. Asseman et al. reported an increased CoP average velocity in SLS (77% increase), but not in PS [14]. They recruited trained gymnasts, possibly explaining the smaller effect of vision elimination on CoP velocity. This is in line with our study, which reported an increase in CoP mean velocity after vision removal for 71% and 58% in PS and narrow PS respectively. This study showed different effects of vision elimination than the present study. The main difference...
between the two studies was that they used only one shorter (20 s) trial to assess body sway [15]. This could have influenced the reliability of the body sway parameters measured [26].

An important observation from this study was a specific effect of vision elimination on the m–l amplitude and velocity in different stances. These two parameters increased dramatically from PS to STS but not from STS to TS and SLS when vision was removed. This was in contrast to amplitude and velocity in the a–p direction, where the effect of vision increased almost linearly towards narrower stances. The increased role of active balance stabilizing mechanisms (i.e. hip neuromuscular system) in narrower stances might explain the differences observed between the traditional parameters in m–l and a–p directions. This is a consequence of a decrease in the mechanical efficiency of passive balance stabilizing mechanisms (i.e. skeletal and joint system) in narrower stances. Due to a higher muscle mass involved, muscle proprioceptive sensory input might have been increased and have compensated for the loss of vision [19]. Additionally, joint and vestibular sensory input might have been increased due to increased sway amplitude [18], and additionally compensated for the loss of vision.

Although body sway increased, the speed of reactive control of body sway proved to be independent of vision and stance type as suggested by unchanged frequency. These results support the predictions of the balance model described by Winter et al. [18] but are in contrast to the model results of Chiari et al. [17] in their study.

vision removal resulted in increased CoP mean frequency during PS. The rapidity of the reactive body sway control can be increased by improved anticipation of the forthcoming body sway [9,18,27]. The rapidity of body sway control seems to be affected by other factors that were not of importance in this present study.

Parameters calculated from RQA were also sensitive to vision elimination, but to a much lesser extent than the majority of the traditional parameters. The effect of vision elimination was absent in the PS, although it was fairly constant in other stances. RQA is a nonlinear method that determines the re-occurrence of CoP movement path or its probability. These results suggest that the CoP movement became more deterministic when vision was eliminated. The trapping time was the only parameter not to be affected by vision elimination. This parameter determines the time CoP is in a specific position during the trial. This supports the above described observation of unchanged frequency of CoP movement. The more rapid reactive compensations for body oscillation would result in an increase in the trapping time. The recurrence of CoP positions in a recurrence plot increased as indicated by increased determinism. These observations are in agreement with the reports of EC-related increased determinism by Lysholm et al. [28]. This could be due increased average amplitude of CoP movement. Results of RQA support the above presented thesis of unchanged rapidity of the reactive control of body sway under EC conditions.

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Parameter</th>
<th>Vision</th>
<th>Stance</th>
<th>PS</th>
<th>STS</th>
<th>TS</th>
<th>SLS</th>
<th>F values</th>
<th>RANOVA</th>
<th>S × V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard/traditional CoP analysis</td>
<td>Velocity (m–l) [mm/s]</td>
<td>EO</td>
<td>11.2 (5.3)</td>
<td>27.5 (11.0)</td>
<td>47.7 (16.7)</td>
<td>79.9 (26.3)</td>
<td>173.1*</td>
<td>47.2 (14.9)</td>
<td>202.2*</td>
<td>47.2 (14.9)</td>
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<td></td>
<td>Velocity (a–p) [mm/s]</td>
<td>EO</td>
<td>6.6 (3.1*)</td>
<td>9.3 (3.0*)</td>
<td>15.2 (6.9*)</td>
<td>22.0 (8.2*)</td>
<td>110.8*</td>
<td>74.0*</td>
<td>129.9*</td>
<td>129.9*</td>
</tr>
<tr>
<td></td>
<td>Amplitude (m–l) [mm]</td>
<td>EO</td>
<td>3.2 (1.5*)</td>
<td>5.9 (1.5*)</td>
<td>8.3 (2.6)</td>
<td>11.4 (3.6*)</td>
<td>148.6*</td>
<td>109.2*</td>
<td>222.4*</td>
<td>222.4*</td>
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<td>Amplitude (a–p) [mm]</td>
<td>EO</td>
<td>4.5 (1.8*)</td>
<td>6.0 (1.7*)</td>
<td>7.7 (3.2)</td>
<td>11.6 (3.7*)</td>
<td>60.6*</td>
<td>75.1*</td>
<td>155.2*</td>
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<td>Sample entropy</td>
<td>Sample entropy (m–l) [a.u.]</td>
<td>EO</td>
<td>0.89 (0.04)</td>
<td>0.91 (0.03)</td>
<td>0.87 (0.05)</td>
<td>0.81 (0.04)</td>
<td>58.4*</td>
<td>16.9*</td>
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<td>Sample entropy (a–p) [a.u.]</td>
<td>EO</td>
<td>0.92 (0.03)</td>
<td>0.89 (0.03)</td>
<td>0.86 (0.05)</td>
<td>0.85 (0.04)</td>
<td>64.8*</td>
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<td>64.8*</td>
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<td>Recurrence quantification analysis</td>
<td>Determinism (m–l) [a.u.]</td>
<td>EO</td>
<td>94.6 (1.7)</td>
<td>95.2 (1.4*)</td>
<td>95.4 (1.4*)</td>
<td>95.6 (1.1*)</td>
<td>25.9*</td>
<td>6.5*</td>
<td>74.9*</td>
<td>74.9*</td>
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<td></td>
<td>Determinism (a–p) [a.u.]</td>
<td>EO</td>
<td>92.6 (2.1)</td>
<td>92.4 (1.9*)</td>
<td>92.1 (1.6)</td>
<td>93.6 (1.5*)</td>
<td>18.8*</td>
<td>10.3*</td>
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<td>10.3*</td>
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<td></td>
<td>Linearity (m–l) [a.u.]</td>
<td>EO</td>
<td>92.8 (1.9)</td>
<td>94.0 (1.4)</td>
<td>93.9 (1.6)</td>
<td>94.9 (1.2)</td>
<td>10.5*</td>
<td>10.5*</td>
<td>10.5*</td>
<td>10.5*</td>
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<td>Linearity (a–p) [a.u.]</td>
<td>EO</td>
<td>0.12 (0.01)</td>
<td>0.13 (0.01)</td>
<td>0.13 (0.01)</td>
<td>0.13 (0.01)</td>
<td>35.0*</td>
<td>9.5*</td>
<td>35.0*</td>
<td>9.5*</td>
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<tr>
<td></td>
<td>Entropy (m–l) [a.u.]</td>
<td>EO</td>
<td>0.12 (0.01)</td>
<td>0.13 (0.01)</td>
<td>0.13 (0.01)</td>
<td>0.13 (0.01)</td>
<td>6.7*</td>
<td>7.6*</td>
<td>6.7*</td>
<td>7.6*</td>
</tr>
<tr>
<td></td>
<td>Entropy (a–p) [a.u.]</td>
<td>EO</td>
<td>2.1 (0.1*)</td>
<td>2.1 (0.1*)</td>
<td>2.1 (0.1*)</td>
<td>2.1 (0.1*)</td>
<td>3.8*</td>
<td>2.3*</td>
<td>3.8*</td>
<td>2.3*</td>
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<tr>
<td></td>
<td>Laminarity (m–l) [a.u.]</td>
<td>EO</td>
<td>72.9 (7.5)</td>
<td>71.1 (5.2*)</td>
<td>72.9 (6.3*)</td>
<td>74.7 (4.6*)</td>
<td>11.5*</td>
<td>2.8*</td>
<td>11.5*</td>
<td>2.8*</td>
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<td></td>
<td>Laminarity (a–p) [a.u.]</td>
<td>EO</td>
<td>65.9 (9.1)</td>
<td>66.7 (6.6*)</td>
<td>67.0 (6.4*)</td>
<td>70.2 (5.8*)</td>
<td>24.1*</td>
<td>9.5*</td>
<td>24.1*</td>
<td>9.5*</td>
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<tr>
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<td>Trapping (m–l) [a.u.]</td>
<td>EO</td>
<td>0.12 (0.04*)</td>
<td>0.09 (0.01)</td>
<td>0.09 (0.02)</td>
<td>0.09 (0.01)</td>
<td>0.81</td>
<td>4.9*</td>
<td>0.12</td>
<td>4.9*</td>
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<td>Trapping (a–p) [a.u.]</td>
<td>EO</td>
<td>0.10 (0.01)</td>
<td>0.09 (0.01)</td>
<td>0.08 (0.01)</td>
<td>0.08 (0.01)</td>
<td>12.4*</td>
<td>2.8*</td>
<td>12.4*</td>
<td>2.8*</td>
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</tbody>
</table>
Interaction between vision removal and change in stance width and shape was an important observation of this study. The interaction effect was significant for the majority of the CoP parameters, but was most prominent for the traditional parameters. The traditional parameters in m–l and a–p direction differed in the linearity of the interaction, especially in narrower stances. The nonlinear interaction effects were also present in RQA parameters. The nonlinearity of the interaction between vision and stance type may have been more efficiently compensated for the removal of vision. The nonlinearity in m–l traditional parameters suggests that the most pronounced sensory re-weighting occurred in TS, by preventing any additional or potentiating sensory deficit after removing vision. The results partially confirm our thesis. The effect of vision removal on traditional parameters in a–p direction increased linearly with change in the width and shape of the stance. However the nonlinear effects of vision removal on traditional parameters in the m–l direction suggest some sensory re-weighting took place, possibly partially compensating for the loss of vision.

The observations of this study might be of interest for measuring balance in the elderly. Increased m–l movement has been shown to be associated with higher risk of falling [25, 30]. Based on our results, using TS measured with EO and EC can additionally assess the quality of balance control and sensory re-weighting in elderly.

5. Conclusion

This study confirmed effects of vision elimination and changes in stance type on the most reliable, traditional, RQA and entropy parameters of body sway. The nonlinear interaction between vision and stance for the traditional parameters in m–l direction suggest that removal of vision can be partially compensated for by other sensory systems. The significant increase in the contribution of other sensory systems seems to occur in TS. This observation is especially of interest for identifying those at risk of falls in the elderly or patient populations, where increased m–l body sway is correlated with risk of falling. By adopting these stances in balance tests, effectiveness of sensory re-weighting after removing vision can be more effectively studied.

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