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

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ABSTRACT

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.

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

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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-eight healthy volunteers participated in the study (24 men, 14 women; age [mean ± standard deviation] 27.6 ± 6.0 years; body height 176.9 ± 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 33.9 ± 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 non-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 (heal-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-min 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 (HE600600-2K 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 average amplitudes of CoP sway 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 deterministic 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 from 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 0%).

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. Benjuya et al. 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