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Sensory Conflict Influence on Functional Reach Performance and Dynamic Standing Balance

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ABSTRACT: Adequate integration of sensory information from different modalities is essential for standing balance. Inadequate and/or incongruent information inputs cause sensory conflict which endangers equilibrium. That is even more expressed during dynamic suprapostural tasks, such as functional reach (FR). Our aim was to study the influence of sensory conflict on FR performance and dynamic standing balance steadiness. Ten healthy right-handed adults performed FR standing on a pedobarographic platform in four sensory conditions: eyes-open (EO), eyes-closed (EC), head in maximal extension and eyes open or closed (EO-HE/EC-HE), adding conflict of vestibular origin. Data were analyzed by Two-Way RM Anova and paired t-test. Factor vision was significant, while only a tendency for head position was found for FR, which shortens in EC, EO-HE and especially EC-HE. For center of pressure (COP) sway path both vision and head position were significant factors. Sway path increased in both EC conditions compared to EO, respectively. Head extension also increased sway path, differences were found between EC and EC-HE. The longest sway path was in EC-HE. Only vision was significant for medio-lateral (M-L) COP sway, which increased in EC compared to EO, respectively. Again, the greatest sway was in EC-HE. The increased COP sway path and M-L sway correspond with decreased FR performance. All these results suggest that absence of vision and/or inadequate vestibular information input, deteriorate dynamic standing balance and task performance, which is expressed the most when both sensory modalities are affected. Factor head position was significant for forward and backward COP velocities (when subjects reach forward and return to initial position). For forward velocity there was significant diminution only between EC-HE and EO, for backward velocity – between EO and both HE conditions. These results suggest that altered vestibular information probably causes velocity decrease. Accuracy of return from FR to initial COP position was greater in EC than in EO. This may be explained by increased weight of proprioception in absence of visual information and/or increased confidence in its presence. Our study suggests a correlation between balance steadiness and suprapostural task performance during sensory conflict. Absence of vision has more impact than altered vestibular information in all cases but for the decrease in FR task dynamics.

KEYWORDS: Postural sway, suprapostural task, sensory integration, center of pressure

1. Introduction

Stance maintenance is a complex sensory-motor task. It is essential that the visual, vestibular and somatosensory information are integrated by the brain as a unified percept,[1] so that adequate muscles' responses to be achieved. When sensory information from different modalities is inadequate and/or incongruent (as during sensory conflict) optimal postural response is impeded.[2,3] Maintaining dynamic standing balance during suprapostural task movements is even more complex. An example of such dynamic task is functional reach (FR). It is the difference between arm's length and maximal forward reach, using a fixed base of support.[4] The test was developed by Duncan et al. in 1990 to estimate the risk of falling of elderly people. It has many modifications up to date as it proves to be a simple, fast, reliable and low-cost method[5-8] for dynamic balance assessment. However, little is known about the influence of sensory conflict and reweighting on FR. The aim of the present research was to explore the influence of sensory conflict on a dynamic standing task, such as FR, via pedobarographic measurements.

2. Methods

2.1. Subjects

This study was approved by the local ethics committee. Ten healthy adults (six males and four females, aged 31.8±10.4 years) took part in the experiments after signing an informed consent. All volunteers were right-handed according to a modified Annett's test.[9]

2.2. Experimental procedure

The dynamic task was performed in four different sensory conditions. The first one is the most informative – eyes-open (EO). The second one aims to explore the impact of absence of visual information – eyes-closed (EC). The third and the fourth conditions are designed to make the vestibular information inadequate. This happens when the subject keeps their head in maximal extension, which puts the utricular otoliths and vestibular cannels into a disadvantageous position,[10-11] thus altering vestibular information. The third condition is eyes-open, head maximally extended (EO-HE). The fourth one is eyes-closed, head maximally extended (EC-HE), during which both vestibular and visual information inputs are deteriorated.

Subjects went through a short training (one to three trials in each condition) before the experiment. Then they were asked to stand barefoot on the platform with feet in a preferred position, make fists and stay for several seconds in the required sensory condition with both arms together in parallel, in horizontal position and elbows extended. Another several seconds after the beginning of the recording, they were commanded to reach forward as far as they could. After holding in the furthest position for three seconds, they were told to return to initial position. No lifting the heels or bending the knees was allowed in trials.

During the experiments each person did two trials in the previously explained conditions. Subjects had sufficient time to rest in sitting position between series.

2.3. Measures and data analysis

Functional reach was measured in mm with a ruler, 1000 mm long. The initial and final positions of the distal end of the third metacarpal were used as markers, the differences between those two values is FR. For each individual the higher value of two trials in the same condition was taken as their maximal FR.

Data of center of pressure (COP) were recorded by a pedobarographic platform Tekscan Evolution (Tekscan Inc., South Boston, MA, USA), provided with Research Software and Sway Analysis Module (SAM) Matscan (Tekscan Inc., South Boston, MA, USA). The recording of each trial lasted 30s with sampling rate 30 frames per second.

The measures calculated by SAM were mean COP sway in anterior-posterior and medio-lateral directions (A-P and M-L sway) and overall COP sway path. The anterior-posterior excursions of COP vs. time (Fig.1) were used to calculate the fast initial forward and backward return velocities of COP displacement by a custom-made program in MatLab (version 7.13). The same program calculated mean initial level of COP before FR start and mean return level after the dynamic task. The

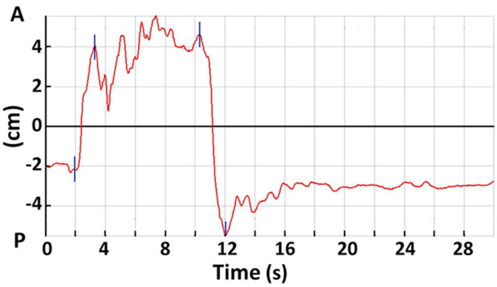

Figure 1: Anterior (A) and posterior (P) excursions of COP in cm during functional reach. Vertical blue lines indicate: start and end of the fast initial forward displacement of COP; start and end of the fast backward return displacement of COP.

difference in mm between those two levels was calculated, as well.

Descriptive statistics and Two Way RM Anova (with two factors: vision and head position) were applied for all measures. Paired t-test for dependent samples was applied afterwards for: FR, COP sway path, A-P and M-L COP excursions and initial forward and backward return velocities of COP. The differences between initial and return levels of COP were analyzed by one sample t-test vs. zero. $P<0.05$ was taken as statistically significant in all cases.

3. Results and discussion

3.1. Functional reach

Two-Way RM Anova for functional reach data revealed that factor vision is statistically significant ($p=0.037$), while for factor head position there was a tendency to be significant ($p=0.07$). No interaction between the two factors was found ($p=0.495$). These results suggest that sensory conflict impedes dynamic task performance (FR), especially during absence of vision.

The results of paired t-test showed that FR length decreases significantly in the EC and the two head-extended conditions (EO-HE and EC-HE) compared to EO (Fig.2). The greatest deteriorating effect of sensory conflict on FR is observed when both sensory modalities are affected (EC-HE).

3.2. Sway path of COP

Considering the overall sway path of COP, both factors – vision and head position, turned out to be statistically significant, by Two Way RM Anova ($p=0.001$ for factor vision and $p=0.016$ for factor head position). No interaction

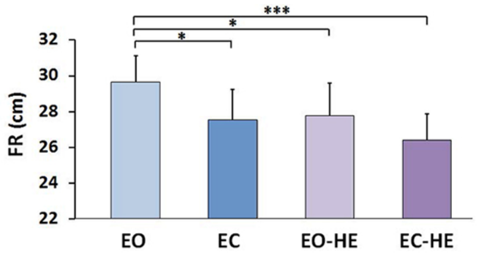

Figure 2: Means and standard errors of mean (SEM) of the length of maximal FR in different sensory conditions. Significant differences between series are shown: * - p<0.05; ** - p<0.01; * - p<0.001, paired t-test.**

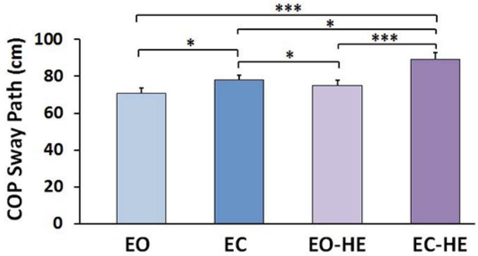

Figure 3: Means and standard errors of mean (SEM) of the sway path of COP in different sensory conditions. Significant differences between series are shown: * - p<0.05; ** - p<0.01; * - p<0.001, paired t-test.**

between the two factors was found (p=0.441).

The results of paired t-test showed that the COP sway path during functional reach increases significantly in both eyes-closed conditions (EC; EC-HE) compared to their corresponding eyes-open conditions (EO; EO-HE). Head extension also leads to increased sway path. Significant differences were found between EC and EC-HE, as well as between EO and EC-HE, EC and EO-HE (Fig. 3). Again, the greatest deteriorating effect of sensory conflict on standing balance steadiness is observed when both sensory modalities are affected (EC-HE).

These results suggest that absence of vision, as well as inadequate vestibular information input, deteriorate dynamic standing balance, which is expressed the most when both sensory modalities are affected. It is worth noticing that the deterioration of balance shown by increased COP sway path corresponds with FR decreased task performance (see also Fig.2).

3.3. Medio-lateral sway of COP

No statistically significant differences in anterior-posterior sway were found, and no visible tendency was apparent. This is most probably due to the mixing of fast forward and backward COP displacements from the dynamic task with static A-P sway, typical for quiet stance.

When exploring the medio-lateral (M-L) sway of COP, Two Way RM Anova revealed that factor vision is statistically significant (p=0.001), while head position is not (p=0.952). No interaction between the two factors was found (p=0.124).

The results of paired t-test showed that the M-L COP sway during functional reach increases significantly in the eyes closed (EC; EC-HE) compared to their corresponding eyes-open (EO; EO-HE) conditions (Fig.4). Significant differences were also found between EC and EO-HE, as well as between EO and EC-HE (Fig.4).

In general, these results are similar to those for COP sway path concerning factor vision (cf. Figs. 3, 4), including the observed great decrease in M-L postural steadiness when both sensory modalities are affected (EC-HE). However, the results for these two stabilographic measures differ concerning factor head position, as it was definitely statistically non-significant.

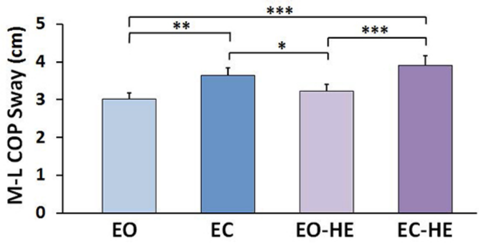

Figure 4: Mean and standard error of mean (SEM) medio-lateral (M-L) sway of COP. Significant differences between series are shown: * - p<0.05; ** - p<0.01; * - p<0.001, paired t-test.**

3.4. Forward and backward COP velocity

Two-Way RM Anova for forward and backward velocity of COP revealed that factor head position is statistically significant (p=0.040 for forward velocity and p=0.005 for backward velocity). There was a tendency for factor vision to be significant for forward velocity (p=0.057), while it was not statistically significant for backward velocity (p=0.542). There was no interaction between the two factors for both measures (p=0.808 and p=0.536).

After paired t-test evaluation for the forward velocities of COP, significant diminution was found only between EC-HE and EO conditions (Fig.5).

For the backward velocities of COP, significant diminution was found for both head extended conditions (EO-HE, EC-HE) compared to EO (Fig.5).

These similar results for both velocity measures during the head extension conditions suggest that altered vestibular information is the most probable cause for the decrease in FR task dynamics.

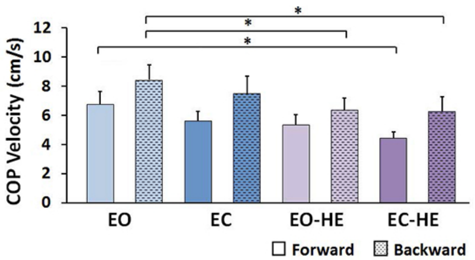

Figure 5: Mean and standard error of mean (SEM) forward and backward velocity of the COP. Significant differences between series are shown: * - p<0.05; ** - p<0.01; * - p<0.001, paired t-test.**

3.5. Difference between initial and return levels of COP

Two-Way RM Anova for the difference between initial and return levels of COP revealed that factor vision is statistically significant (p=0.032), while factor head position is not (p=0.835). There is no interaction between the two factors (p=0.821).

In both eyes open conditions when returning to normal position after dynamic task completion, COP goes more backwards compared to its initial level (Fig.6).

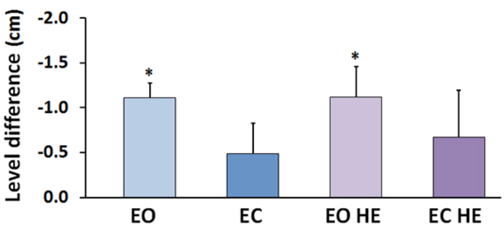

Figure 6: Means and standard errors of mean (SEM) of the difference between the initial and return levels of COP during functional reach. Significant differences from zero are shown: * - p<0.05; ** - p<0.01; * - p<0.001, one sample t-test vs. zero.**

The evaluation after one sample t-test showed that it is statistically significant. However, there is no significant difference between initial and return levels during both eyes-closed conditions.

These results suggest that probably an increase of weight of proprioception due to reweighting process during eyes-closed occurs, that increases accuracy of return. The overshooting phenomenon observed in both eyes-open conditions may be explained with a greater confidence of subjects while visual information is available.

4. Influence of Sensory Conflict on a Dynamic Standing Task

Our study shows that sensory conflict influences negatively both steadiness of dynamic standing balance and the length of FR, especially when both sensory modalities are affected. In other words there is a correlation between balance steadiness and the suprapostural task achievement during sensory conflict.

The absence of vision has more impact than the deteriorated vestibular information in all cases but for the decrease in FR task dynamics.

An interesting finding is that accuracy of return from FR to initial COP position is greater in the eyes-closed than in the eyes-open conditions, manifested by statistically significant overshooting observed in the latter conditions. This may be explained by increased weight of proprioception in absence of visual information and/or increased confidence of subjects in its presence.

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