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Posture, Balance and the Brain

EEG Sources during Quiet and Sensory-Conflicted Stance

Plamen Gatev[a], Katerina Stambolieva[a], Jordanka Lalova[b] and Bozhidar Dimitrov[b]

[a] *Institute of Neurobiology, BAS, Acad. G. Bonchev Str., Bl. 23, Sofia 1113, Bulgaria*

[b] *Inst. of Population and Human Studies, BAS, Acad. G. Bonchev Str., Bl. 6, Sofia 1113, Bulgaria*

ABSTRACT: We studied the changes in the standing balance and the EEG sources locations during quiet stance with eyes-open (EO) and sensory-conflicted stance while standing: with eyes-closed (EC – absence of vision); with eyes-open and head maximally extended (EO_HE – inadequate vestibular information); with eyes-closed and head maximally extended (EC_HE–absence of vision, aggravated by inadequate vestibular information). An increase of sway path during stance without vision was registered mainly due to increased anteroposterior sway, while in the head-extended series we found increased mediolateral sway. We also found differences in the locations of EEG sources between series with different sensory conditions, which suggest cortex involvement in a different way for solving sensory conflict from different origins, that is supported by the different postural changes, as well. The EEG sources during standing with EO were located in the medial frontal gyrus (MFG), anterior cingulate cortex (ACC), precuneus and cuneus, while the EEG sources during EC were near the same cortical areas, but the ACC source was absent. The EEG sources during EO_HE were revealed to be in ACC, precuneus and cuneus, but not in the MFG like during standing with EO. During standing with inadequate vestibular information new sources appeared in the left superior and medial temporal gyrus in both series with eyes-open and eyes-closed. During the last series, when both modalities were producing the sensory conflict, ACC source was also present but precuneus and cuneus sources were absent, compared to the series with only vestibular conflict. Our results support the hypothesis of cortical regulation of quiet stance and changes in this regulation during sensory-conflicted stance, which depends on the modality of sensory conflict.

KEYWORDS: Standing balance, sensory conflict, cortex, LORETA

1. Introduction

The maintenance of human quiet standing balance is a difficult task because of the highly positioned center-of-gravity (COG) that makes the equilibrium unstable. Furthermore, it is a complex sensory-motor task because no one sense provides information about the position of COG, which is the main controlled parameter obtained by a multisensory integration. The main task of this integration is to minimize perceptual ambiguity by exploiting cross-sensory congruence and reweighting of the senses in order to reach a coherent unified percept of the body and its parts related to the external environment, adequate to the internal goals, task and biomechanical constraints.[1] Thus, the standing balance information, coming from sources with different modalities and dimensions: visual, somatosensory, vestibular, etc., should be combined, going through a complex interplay between sensory-specific cortices into multisensory brain areas,[2] as well as between the imagery and perception itself,[3] attention reallocation[4] and gating processes.[5] All of the mentioned above assumes increased brain effort, especially during sensory-conflicted stance. Our main goal was to apply low resolution electromagnetic tomography (LORETA),[6-7] a well-established model, to find current density estimation and locations of scalp EEG sources during quiet and sensory-conflicted stance. We also did simultaneous evaluation of postural sway changes, as well as psychometric tests of laterality, personality and intelligence.

2. Methods

2.1. Subjects

This study was approved by the local ethics committee. Seven healthy volunteers (3 females, 4 males, aged – mean 28.6 yrs., SD +/-4.7 yrs.) took part in the experiments, after signing an informed consent. All experimental subjects were right-handed according to a modified Annett's test.[8] Psychometric tests for personality – Eysenck personality questionary,[9] and for intelligence – Raven Progressive Matrices Test,[10] were conducted.

2.2. Experimental procedure

The experimental task was standing on 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). Subjects stood as steady as possible with heels separated by 3 cm and forward inclination of 30° for the toes and arms freely hanging alongside the body. Four experimental series with different sensory conditions were performed in a random order and with sufficient rest in a comfortable sitting position between them. The first series was quiet stance with eyes-open (EO), where sensory inputs from all modalities were available. The second one aimed to explore the impact of absence of visual information – eyes-closed (EC). In the third series (standing with eyes-open with head-extended – EO_HE) the vestibular information was made inadequate. This occurs when the subject keeps their head in maximal extension, which puts the utricular otoliths and vestibular cannels into a disadvantageous position,[11] thus altering vestibular information. During the fourth series – standing with eyes-closed with head-extended (EC_HE) sensory conflict from vestibular origin was aggravated by absence of vision. For each condition three trials were done and the center-of-pressure (COP) sway path was recorded. The recording of each trial lasted 30s with sampling rate 30 frames/s.

The electroencephalogram (EEG) was registered simultaneously with COP recording by 19 scalp electrodes attached on the scalp in accordance to the 10-20 of the IFCN on a 24 channel MITSAR 202 EEG machine (Mitsar Medical, Petersburg, Russia), with bandwidth 0.5-70 Hz and sampling rate of 500 Hz. We did off-line artifacts removal by the WINEEG software. The current density sources were estimated with LORETA. We mapped the locations of maxima of current density of EEG sources during the four condition series.

Postural sway measures calculated by SAM were overall COP sway path and mean COP sway in anteroposterior and mediolateral directions (AP and ML sway).

3. Results and Discussion

The results showed that the overall sway path increases during absence of vision in both EC and EC_HE series (Fig.1).

Separate measures of AP and ML mean sway showed that the increased sway path when vision is absent – during EC compared with EO is due to the ML sway

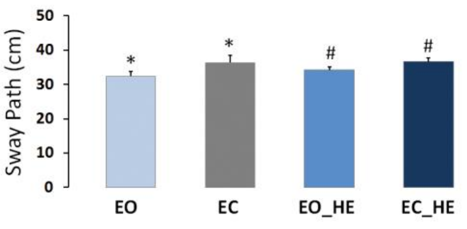

Figure 1: Means +/- SEM of the overall sway path of the COP during standing in four sensory conditions. P<0.05, statistically significant difference is between columns with the same statistical signs.

(Fig.2). Inadequate vestibular information during EO_HE and EC_HE led to the increase of AP sway compared with EO and EC series respectively (Fig. 2).

The results from LORETA (Fig.3) show that the EEG sources during standing with EO are located in the medial frontal gyrus (MFG), anterior cingulate cortex (ACC), precuneus and cuneus, while the EEG sources during EC are near the same cortical areas, but ACC is not present (Fig.3). The anterior cingulate cortex (ACC) and adjacent areas of the medial frontal cortex (MFC) have been implicated in monitoring behaviour and in detecting errors. Furthermore, dorsal MFC areas also control response selection, when the current task is changing, serving the extroverted attention during monitoring an ongoing task, selecting an appropriate response, and suppressing inappropriate responses.[12] The results are also in line with findings that MFG shows great connectivity with dorsal-posterior precuneus and belongs to the dorsal precuneus and cuneus network.[13]

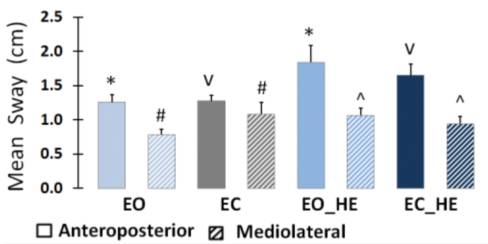

Figure 2: Means +/- SEM of the anteroposterior (left solid columns) and mediolateral (right, strike patterned columns) sway of the COP during standing in the 4 sensory conditions. P<0.05, statistically significant difference is between columns with the same statistical signs.

The EEG sources during EO_HE were found to be in ACC, precuneus and cuneus, but not in the MFG likewise during standing with eyes open and normal head position (Fig.4). During standing with EO_HE sources in the left superior and medial temporal gyrus appeared.

EEG sources during EC_HE were located in the ACC and again in the left superior and medial temporal cortex areas. The results support the hypothesis for a wide fronto-temporal-parietal network involved in the top-down control of spatial attention.[14] Since the last two series with sensory conflicted stance included inadequate vestibular information, it is interesting to note they revealed EEG sources in the left superior and medial temporal cortex. It is a part of the widely distributed network of vestibular cortex that overlaps with multisensory presentation from vision, somatosensation, proprioception and action.[15] The integration of visual and vestibular information by MSTd is essential for real-world navigation, in which the interplay between object motion, optic flow, and self-motion can produce potentially ambiguous signals.[16] The lack of such sources in the right hemisphere of right-handed subjects might be due to the suppression of vestibular signal processing in favour of potentially conflicting-visual input.[17] An alternative is that inadequate vestibular information is processed by ontogenetically older left hemisphere structures, like in rats.[18]

The results from LORETA show that there are differences between the locations of EEG sources during stance with conflicting sensory conditions. Most of our knowledge about the neuroanatomy of the cortical networks comes from the fMRI, NIRS and PET studies where brain activity correlates with the blood flow, while the EEG is based on electrical phenomena and in many cases the brain work is connected with desynchronization, which lowers the amplitude and is an obstacle for the right interpretation of the results. Nevertheless, our results support the hypothesis of cortical regulation of standing balance,[19-22] thus adding quiet stance as a cortically regulated task. Moreover, the results suggest changes in this regulation during sensory-conflicted stance, which depends on the modality producing sensory conflict.

We did not find any significant correlation between personality traits or intelligence scores and postural sway measures or source locations.

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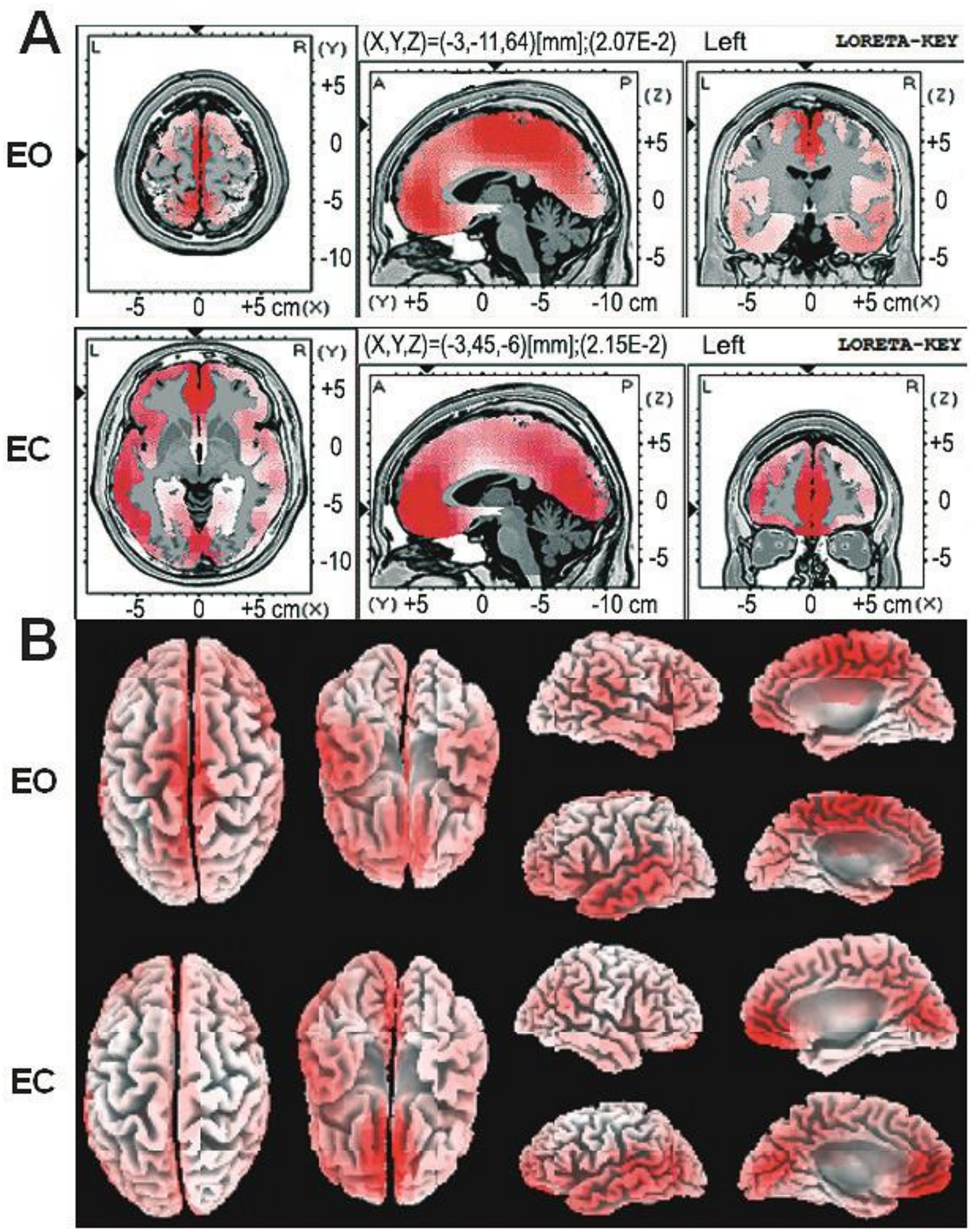

Figure 3: Data from LORETA model. A: Location of sources of the EEG activity during standing with eyes-open (EO) and eyes-closed (EC) conditions in Talairach coordinates in mm; horizontal, sagittal and frontal plane views. B. 3D views: two cortical hemispheres views from the top and from the bottom; Right hemisphere (top), left hemisphere (bottom), views from outside and from inside.

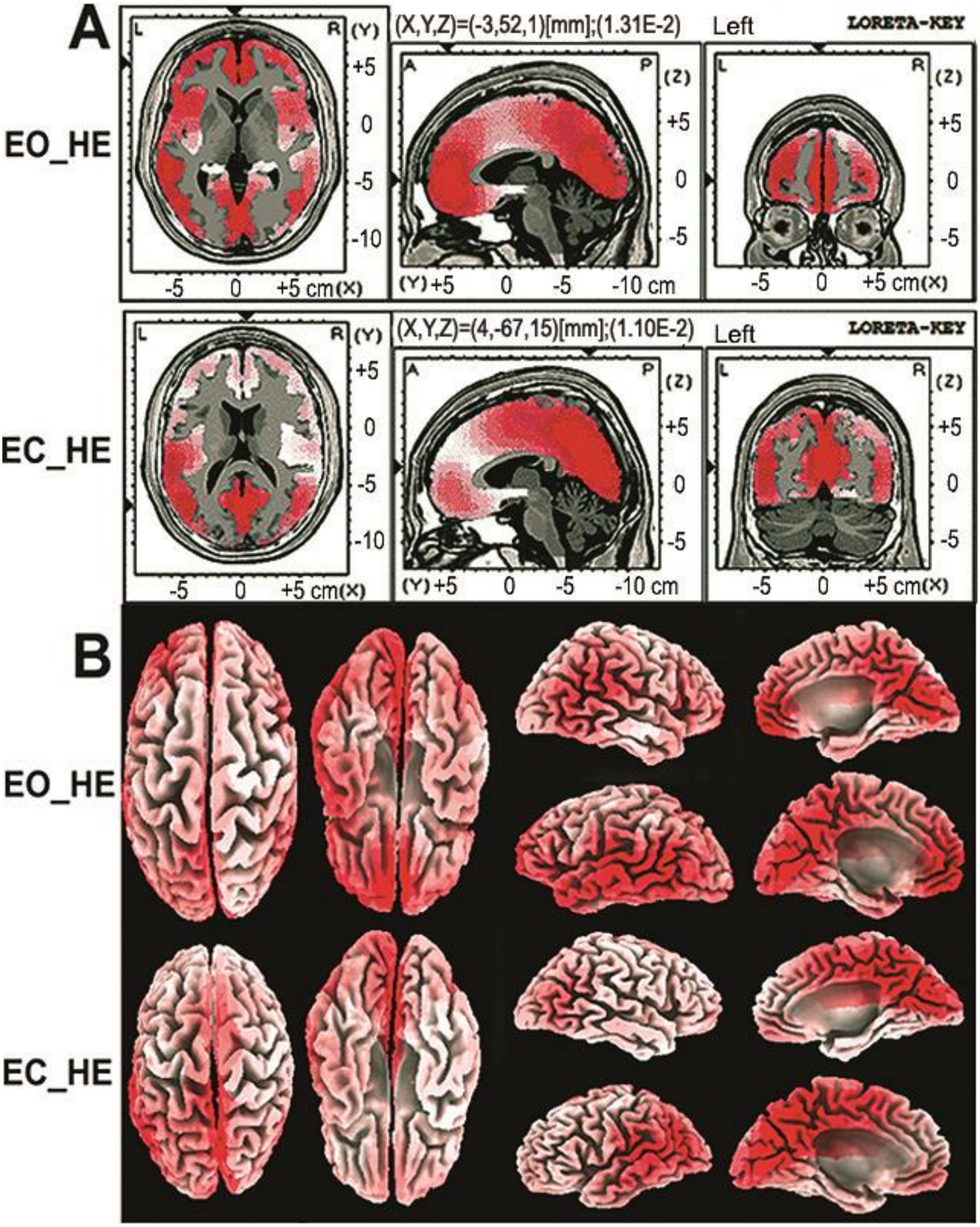

Figure 4: Data from LORETA model. A: Location of sources of the EEG activity during standing with eyes-open and head extended (EO_HE) and eyes-closed and head extended conditions (EC_HE) in Talairach coordinates in mm; horizontal, sagittal and frontal plane views. B. 3D views: two cortical hemispheres views from the top and from the bottom; Right hemisphere (top), left hemisphere (bottom), views from outside and from inside.

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