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The human balance system and gender

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The human body balance system is a complex system of organs and mechanisms, which generate postural reactions to counter the displacement from the equilibrium position of the body centre of gravity, and which control eye movement in order to maintain a stable image of the environment. Computerised Dynamic Posturography (CDP) allows for a quantitative and objective assessment of the sensory and motor components of the body balance control system as well as of the integration and adaptive mechanisms in the central nervous system. The aim of this study was to determine the differences, when maintaining body balance, based on the gender of young, healthy people using CDP. The study was carried out on a group of 43 healthy subjects by comparing the effectiveness of the balance system in 22 women and 21 men aged between 20 and 26 years, between 171 and 177 cm in height, and without any clinical symptoms of balance disorders. The men and women were selected such that they did not differ significantly in height and BMI. Using the Equitest posturograph manufactured by NeuroCom International Inc. the following tests were performed: Sensory Organisation Test (SOT), Motor Control Test (MCT) and the Adaptation Test (ADT). The gender of young healthy individuals without any clinical symptoms of balance disorders also does not affect the effectiveness of the sensory system and the use of this signal in maintaining body balance.

Key words: *computerised dynamic posturography, height, weight, BMI, gender, women, men*

1. Introduction

The human body balance system is a complex system of organs and mechanisms, which generate postural reactions to counter the displacement from the equilibrium position of the body centre of gravity, and which control eye movement in order to maintain a stable image of the environment. The location of the body centre of gravity is determined on the basis of information from the vestibular receptors, the visual system and the somatosensory system. This information is delivered to the central nervous system which activates the musculoskeletal system in such a way that the centre of gravity does not extend beyond the boundaries of the base of support, which the feet and the area between them form (Błażkiewicz [1], Iwańska and Urbanik [4], Nashner [9], [7], Piecha et al. [14], Wu et al. [18]).

Computerised Dynamic Posturography (CDP) (Nashner [7]) allows for a quantitative and objective assessment of the sensory and motor components of the body balance control system as well as of the integration and adaptive mechanisms in the central nervous system. CDP consists of several test protocols which include: the Sensory Organisation Test (SOT), the Motor Control Test (MCT) and the Adaptation Test (ADT). The SOT assesses the body balance control under various stimulations of the sensory system, including sensory conflict conditions, i.e., the inflow of conflicting sensory signals. The MCT evaluates postural reactions in response to unexpected platform translations. The ADT evaluates the effectiveness of the adaptive mechanisms in maintaining body balance

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when subjected to changes in platform tilt (NeuroCom International [10]).

The effectiveness of the human balance system is affected by many different factors such as: mental and physical fatigue, neurological disorders, physical exercises, gender, body weight, BMI and age (Faraldo-García et al. [3], Liaw et al. [5], Robillard et al. [15], Oliveira et al. [13]).

The aim of this study was to determine the differences, when maintaining body balance, based on the gender of young, healthy people using computerised dynamic posturography.

2. Materials and methods

The study was carried out on a group of 43 healthy subjects by comparing the effectiveness of the balance system in 22 women and 21 men aged between 20 and 26 years, between 171 and 177 cm in height, and without any clinical symptoms of balance disorders. The men and women were selected such that they did not differ significantly in height and BMI (Olchowik et al. [12], in press). The study was conducted with the approval of the Bioethical Committee for Research at the Medical University of Lublin.

Center of gravity (COG) is positioned at a height equal to approximately 55% of total body height and 14% of foot length in front of medial malleolus bone in the ankle joint. This puts the COG on a line inclined 2.3 degrees forward from a vertical line passing through the ankle joint (NeuroCom International [10]). Since the length of the body of all subjects was within a small range, differences due to the impact of body height were not taken into account.

The subjects were selected from a group of 202 people on the basis of their health, height, body weight and BMI. The health assessment questionnaire contained questions relating to cardiovascular, respiratory, metabolic and neurological diseases as well as other chronic diseases that may affect the balance system.

The questionnaire also took into account vision defects, poor posture and dysfunctionality in the balance system as well as hearing disorders. In addition, questions related to previous injuries, operations, medication and alcohol consumption. Each participant had their height, weight and body mass index (BMI) recorded prior to the posturographic tests.

Using the Equitest posturograph manufactured by NeuroCom International Inc. the following tests were performed: Sensory Organisation Test (SOT), Motor Control Test (MCT) and the Adaptation Test (ADT).

In SOT both the foot support platform, as well as a screen simulating the visual environment can be tilted in response to the patient's swaying. The test was performed using six sensory stimulation conditions (Nashner [7], NeuroCom International [10]):

- Stationary platform and visual surround, eyes open (SOT1) or closed (SOT2),
- Stationary platform, sway-referenced visual surround and eyes open (SOT3),
- Sway-referenced platform, stationary visual surround and eyes open (SOT4) or closed (SOT5),
- Sway-referenced platform, sway-referenced visual surround and eyes open (SOT6).

The computer program controlling platform movement and the visual surround mimicked the displacement of the centre of gravity in the forward–backward direction (NeuroCom International [10]). Analysis was performed to determine: the Equilibrium Score (ES), Sensory Analysis (SRS), Motor Strategy (MS) and the Centre of Gravity Alignment Score.

The ES result provides a quantitative assessment of the displacement of the body centre of gravity in the forward–backward direction. The greater the displacement, the smaller the ES value. The composite equilibrium score (CES) takes into account the displacement of the body centre of gravity under all SOT conditions (Chaudhry et al. [2]).

The SRS results were analysed separately for the somatosensory system (SOM), the visual system (VIS), the vestibular system (VEST) and visual preference (PREF). They testify to the usefulness of the signal from a given sensory system in maintaining body balance. The higher the value, the more effective the given sensory system and its proper use in the maintenance of body balance. The MS result allows muscle activity to be compared between ankle-muscles and hip-muscles. A higher MS value indicates greater ankle-muscle activity (NeuroCom International [10]).

The MCT was performed using a support platform with six degrees of freedom: small forward (SFT), medium forward (MFT) and large forward (LFT) translation as well as small backward (SBT), medium backward (MBT) and large backward (LBT) translation. The screen displaying the visual surround was stationary (Nashner [7], NeuroCom International [10]). The movement of the platform provided a destabilizing stimulus which evoked a postural response. The MCT analysed the latency (LC) – the time between the start of the destabilising stimulus and the start of the postural response, as well as the response amplitude (A) which allows for a direct assessment of the postural response in both lower limbs (Nashner [7], NeuroCom International [10]).

In the ADT, with a stationary visual surround, the platform changes its tilt regardless of the patient's sway (Nashner [7], NeuroCom International [10]). The ADT consists of two series, one of which causes dorsiflexion (ATU) whilst the other plantarflexion (ATD) in the ankles. Each series consisted of five trials. In the first trial for both series the reflex to the stretching increases muscle tension and stiffness in the ankles. In the remaining four trials, the adaptive mechanisms should lead to a decrease in the amplitude of the destabilizing muscle contractions (Nashner [6], [7], [8], NeuroCom International [10]). After each platform perturbation the sway energy is determined (a dimensionless quantity in the range from 0 to 200). The greater the body imbalance caused by the platform perturbation, the greater the displacement of the centre of gravity, and thereby the greater the sway energy.

2.1. Statistical analysis

Statistical analysis was performed using the STATISTICA 7.0 (StatSoft) computer program. To verify that a quantitative variable came from a population with a normal distribution the Shapiro–Wilk test was used. The significance of the differences between the two groups for the quantitative variables was verified using either the *t*-Student test or the Mann–Whitney U test (for those cases where the *t*-Student test criteria were not fulfilled). The results of the evaluation of the significance of the differences were represented by the significance coefficient (p). The level of statistical significance was indicated by: "*" – $0.01 < p < 0.05$, "#" – $p < 0.01$ and "ns" – $p > 0.05$ (statistically insignificant).

3. Results

Figure 1 shows the SOT equilibrium score (ES) results for both groups (women and men). An analysis of body balance showed significant differences only in ES1 values. This parameter was higher for men. No significant differences were found between men and women in the displacement of the centre of gravity in the forward–backward direction for the remaining SOT conditions including the composite equilibrium score (CES). There was also no significant correlation in the SOT results for the somatosensory (SOM), visual (VIS), and vestibular (VEST) systems, as well as the visual preference (PREF) between the men and women (Fig. 2, Fig. 3). The SOT parametric values for the motor strategy (MS) are shown in Fig. 2. It was noticed that the MS was significantly dependent on

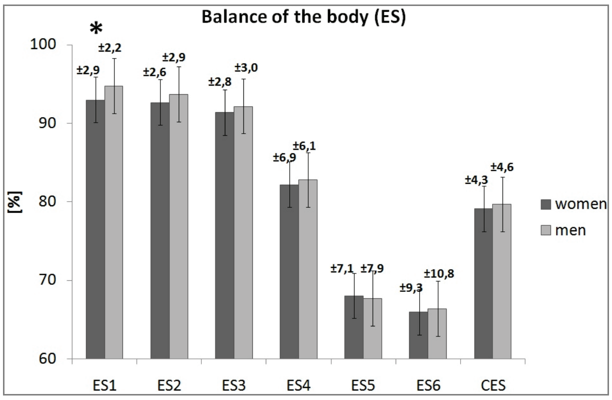

Fig. 1. The results of the balance of the body (ES) in the sensory organization test (SOT1-SOT6) in women and men (±standard deviation, SD) (*– statistically significant, 0.01 < – < 0.05)

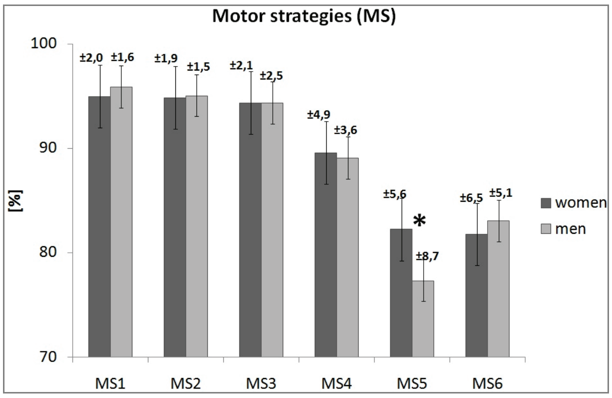

Fig. 2. The results of motor strategies (MS) (SOT1-SOT6) in the sensory organization test in women and men (±standard deviation, SD) (*– statistically significant ($0.01 < p < 0.05$)

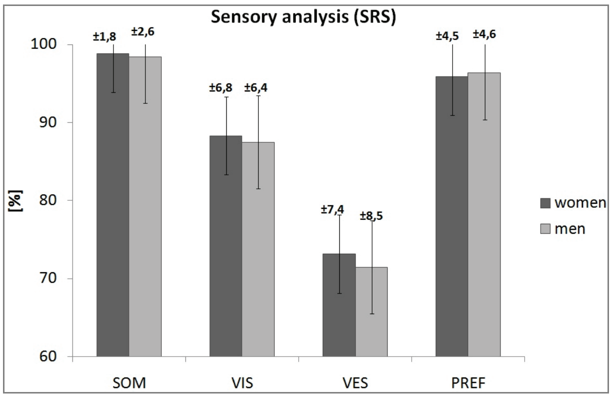

Fig. 3. The results of sensory analysis (SRS) of: the somatosensory (SOM), visual (VIS), vestibular (VEST), visual preferences (PREF) in the sensory organization test in women and men (±standard deviation, SD)

gender only for SOT5 (eyes closed, sway-referenced platform, stationary visual surround). There was no noticeable effect of gender in SOT 1-3 (stationary platform). There was also no significant correlation between the genders for SOT4 (eyes open, sway-referenced platform, stationary visual surround) and SOT6 (eyes open, sway-referenced platform, sway-referenced visual surround).

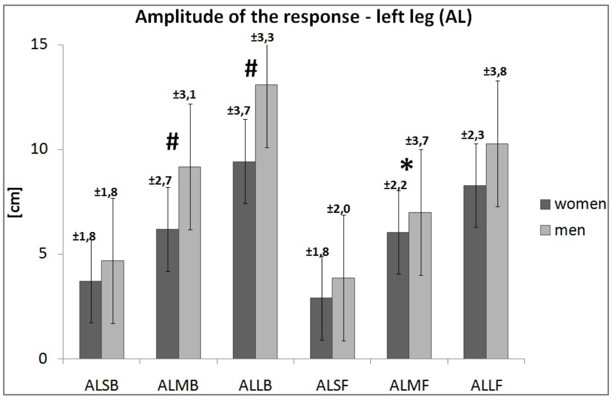

Fig. 4. The amplitude of the response to movement the platform for left (AL) in motor control test (MCT) in women and men (± standard deviation) (*– statistically significant, $0.01 < p < 0.05$; #– statistically significant, $p < 0.01$)

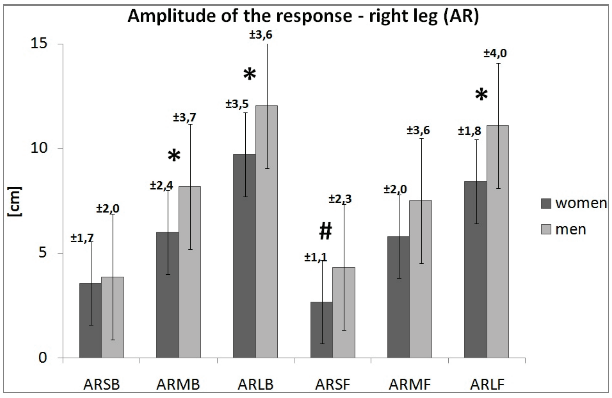

Fig. 5. The amplitude of the response to movement the platform for right leg (AR) in motor control test (MCT) in women and men (± standard deviation) (*– statistically significant, $0.01 < p < 0.05$; #– statistically significant, $p < 0.01$)

The average values for the left (AL) and right (AR) response amplitudes of the lower limbs in response to the platform translations under all MCT conditions for men and women are shown in Fig. 4 and Fig. 5. The amplitude response of both the right and left lower limb was significantly dependent on gender. For medium and large forward and backward platform translations the response amplitudes were greater for men. There was no noticeable effect of gender on the response amplitude of both limbs for small platform translations in both directions. The postural response latency (LC), determined using MCT, was also not dependent on gender (Fig. 4, Fig. 5).

The average sway energy (SE) for both series of trials in the ADT for men and women is shown in Fig. 6 and Fig. 7. The study did not reveal any statistically significant dependences on gender.

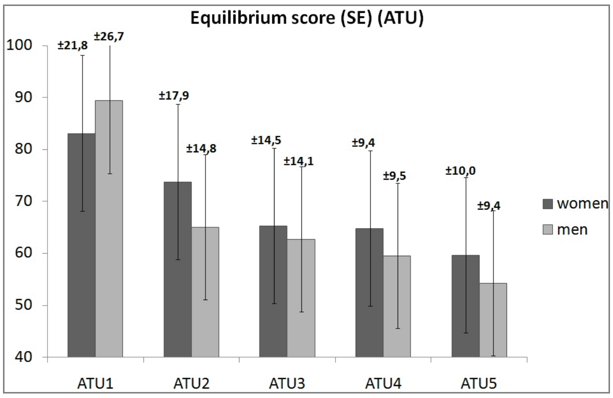

Fig. 6. The results of the equilibrium score (SE) in the adaptation test (ADT) in a series of five rotating platform causing dorsiflexion (ATU1-ATU5) in women and men (± standard deviation, SD)

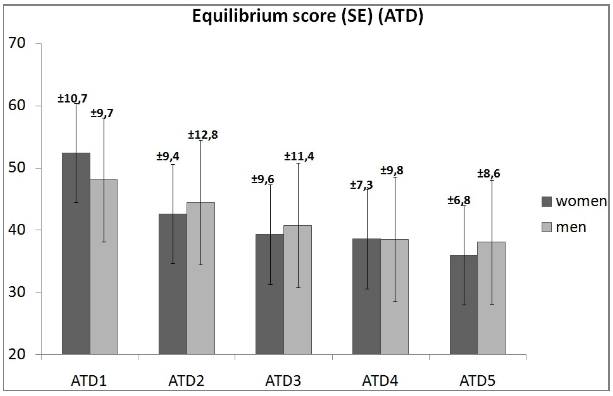

Fig. 7. The results of the equilibrium score (SE) in the adaptation test (ADT) in a series of five rotating platform causing plantarflexion (ATD1-ATD5) in women and men (± standard deviation, SD)

4. Discussion

The study showed a significant correlation between gender and the ES results for SOT1 (Fig. 1) and MS for SOT5 (Fig. 2). Significantly higher ES1 values for men are evidence of smaller displacements of the centre of gravity in the forward–backward direction with the proper information from the eyes and the sensory system. However, for women, higher MS5 values were observed (Fig. 2). In the absence of information from the eyes, women show a greater ankle-muscle activity and lesser hip-muscle activity in comparison to men. Postural response amplitude in both left and right lower limbs was also significantly dependent on gender (Fig. 4, Fig. 5).

For medium and large forward and backward platform translations, causing automatic corrective responses, the response amplitude of both limbs was greater for men. However, no significant differences in postural response latency were observed with respect to gender. It should be emphasised that the groups of subjects were homogeneous in terms of height and BMI.

The resultant body imbalance caused by platform perturbations in the ADT did not differ significantly between men and women (Fig. 6, Fig. 7). The gender of young healthy individuals without any clinical symptoms of balance disorders also does not affect the effectiveness of the sensory system and the use of this signal in maintaining body balance (Fig. 2, Fig. 3).

In the available literature there are no reports on the effect of gender on CDP results for a group of people aged between 20 and 26 years. However, there are reports of these dependences in other age groups. Faraldo-Garcia et al. [3] when conducting research into the posture of 70 healthy subjects aged between 16 and 81 years noticed higher ES1 values for men while ES3 values were higher for women. In a study by Wolfson et al. [17] on 234 persons (52% were women) aged over 70 years the SOT equilibrium score results, based on gender presented themselves differently. ES values for SOT4, SOT5 and SOT6 were lower for women. Under these test conditions a higher incidence of falls was observed in women.

The effect of gender on MS results is also confirmed by the study of Faraldo-García et al. [3]. They showed that already from their 16th year woman make use of their ankle-muscles more effectively than men. These observations, however, concerned only the SOT4 condition and were consistent with the results of Wolfson et al. [17] in subjects whose age was over 70 years. According to Faraldo-Garcia et al. [3] women wearing shoes with higher heels than men, reduce the surface area of the base of support. To maintain body balance under these conditions a better stabilisation in the ankle-joint is necessary. As a result of this daily training it allows for a more effective use of the ankle-muscles in comparison to men. For the remaining SOT conditions the study authors (Faraldo-García et al. [3], Wolfson et al. [17]) did not observe significant differences in the MS results between the genders.

A lack of significant correlation between the test results evaluating the effectiveness of the sensory system and its use in maintaining balance among young, healthy men and women is consistent with the results of the study's authors (Faraldo-García et al. [3]). Neither did Faraldo-Garcia and colleagues observe significant statistical differences in the SRS results between healthy men and women aged between 16 and 81 years.

The sensory organisation is a process in which the signals from the sensory organs are integrated in the central nervous system in order to maintain body balance. These signals are used to determine the position of the body's segments relative to each other and to the environment. The displacement of the centre of gravity from the equilibrium position is also determined. The signals from the sensory organs are used to varying degrees, depending on the stimulation conditions. The greatest contribution is from those which provide the most reliable information about the actual displacement of the body centre of gravity from the equilibrium position (NeuroCom International [10]).

The proper sensory organisation, in maintaining body balance, allows for the use of the most reliable source of information about the position of the body centre of gravity for a given stimulation of the sensory organs. It allows for the suppression of improper signals or the amplification of sensory signals which are in accordance with the actual displacement of the body centre of gravity. It also enables the achievement of high ES values, the proper use of a signal from each sensory source (SOM, VEST, VIS, PREF), the generation of an appropriate MS and ensures the proper compensatory repositioning of the body centre of gravity (NeuroCom International [10], Oliveira et al. [13]).

A greater body weight and an associated greater muscle mass in men enables a more effective generation of the postural amplitude response in men than in women. Response amplitude observations of both limbs are confirmed by Wolfson et al. [17]. They observed a lower amplitude response to large forward platform translations in women compared to men, and shorter response latencies to large platform translations in the forward and backward directions. The latency differences in our observations can be explained in terms of height and weight differences of the men and women taking part in the study carried out by Wolfson et al. [17]. An increase in height results in a longer path for the nerve impulses in long reflex arcs assessed in the MCT and therefore greater latency (Liaw et al. [5]).

The MCT analyses long reflex arcs of central projection (Nashner [7], Nashner [8], NeuroCom International [10]). In these reflexes the signal originating from the proprioceptor muscles and tendons around the ankle-joint, knee-joint, and hip-joint travels into the nuclei of the brainstem, the cortex, the subcortical region and the cerebellum (NeuroCom International [10]). Here integration with signals from other sensory sources occurs. After appropriate correction, the impulses travel from the central nervous system to the body's postural muscles, which generate the postural response (Shepard et al. [16]).

Under ADT conditions, the stretch reflex, which plays an important role in the creation of postural responses and whose main task is to maintain an upright posture has an exceptionally destabilising effect. Measurement of sway energy provides a quantitative assessment of the ability to suppress the destabilising reflex under test conditions due to stretching. This test allows the adaptive mechanisms of the body balance system to be assessed, which occur in the central nervous system (Nashner [7], NeuroCom International [11]). The gender of young, healthy people, not differing significantly in height and BMI, does not affect the displacement of the centre of gravity, and thereby the imbalance caused by platform perturbations which causes flexion and plantarflexion in the ankle-joints. Furthermore, in the ADT, just like Wolfson et al. [17] we observed proper adaptive mechanisms, both in men and women, which resulted in reducing the sway energy in subsequent trials in both series. However, the authors Wolfson et al. [17] reported a higher incidence of falls in the ATU1–ATU4 and ATD1 trials among shorter and lighter women compared to taller and heavier men. According to Wolfson et al. [17] the more frequent falls in women may be due to a lower ability to generate sufficient muscle power to cause movement in the ankle-joint in order to correct the body's silhouette displacement. Another reason could be a greater stiffness in the ankle-joints limiting the scope of dorsiflexion in women over 70 years of age.

The complex relationship between the sensory system and the motor system in maintaining body balance is determined by personal characteristics such as age, height, BMI and gender. An assessment of their interrelationships may allow us to distinguish personal conditions from symptoms that can be diagnosed with the help of computerised dynamic posturography.

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