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Effect of smooth eye tracking in different patterns on results of the modified Clinical Balance Sensory Integration Test in healthy young adults

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Purpose: The aim of the study was to determine whether eye tracking of a point moving in different directions influences balance test performance in young healthy subjects. *Methods*: The study enrolled 45 healthy young adults aged 19–26. Balance assessment was carried out according to the modified Clinical Balance Sensory Integration Test protocol using the Biodex Balance System with an additional 63" screen to present the eye-tracking task. Each participant repeated measurements in standing on a stable and foam surface in six test conditions: two without eye tracking with eyes open and eyes closed, and four with eye tracking: with vertical, horizontal, star, and circle moving point. Each trial lasted 30 sec. *Results*: Regression analysis for the Sway Index showed that there was no impact of eye tracking on test results ($p = 0.4326$), although detailed analysis showed a significant impact of tracking a point moving in a circle in standing on a foam surface ($p < 0.001$). *Conclusions*: The presented results show that eye-tracking does not influence the results of the balance test with exception of eye-tracking of the circle movement in standing on a foam surface. It suggests that eye movements may affect the test results when performing more difficult balance tests.

Key words: *eye movements, postural control, smooth pursuit, mCTSIB*

1. Introduction

Balance testing is an important component of functional assessment, both in healthy individuals of all ages, from athletes to the elderly, and also in different clinical conditions, including neurological, orthopaedic or rheumatology diseases. Good postural balance reduces the risk of sports injuries and their negative consequences on an athlete's performance [2]. Poor body balance is also closely related to the higher risk of falls in the elderly [8]. Quick and effective identification of impaired balance allows for the implementation of exercises that prevent its consequences [25], [26].

Postural control testing is possible using both clinical tests and objective tests on balance platforms [3], [11]. Most researchers prefer tests using objective tools due to their higher reliability and reproducibility [10], [22]. The most commonly used are dynamometer platforms [13], pressure distribution systems [19] or dedicated balance assessment platforms [6]. The preferred test to assess balance on all types of platforms is a free-standing test (both-leg or single-leg stance) with eyes

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open or closed [6]. Limits of stability tests are used relatively frequently [15] while biofeedback tests are used rather rarely [16].

Commonly used tests to assess balance involve a strategy of applying difficulties to assess the performance of particular body systems. Therefore, the postural sway is tested with eyes open or closed, on different types of surfaces (stable, soft or unstable), as well as in different positions (both legs, single-leg or tandem standing) [6], [32]. The external factors might potentially affect body balance, but research results do not support this. For instance, studies regarding noise show its effect on the vestibular system, but no effect on balance parameters [36]. It is worth noting that some papers report the little effect of group membership [13], [34] or treatment intervention on balance test results [1], [12]. Thus, it seems that additional factors related to the testing procedure itself may have a significant impact on the center of pressure (COP) movement and therefore sometimes decide, e.g., whether a therapeutic intervention is effective. However, instructions for the proper performance of tests with visual control are ambiguous, and in descriptions of balance testing methodology available in the literature, this aspect is most often omitted. So far, we found only one paper where the viewing direction was described in the test method [21].

The majority of authors describe only that the balance assessment was performed with eyes open or closed. Meanwhile, in the literature, there are studies which show that eye movements can alter postural control parameters. Rodrigues et al. [29] showed that the type of eye movement (saccadic or smooth) can have a significant impact on body sway. Some studies show that saccadic eye movements compared to observing a stable point do not affect postural sway [37], while smooth eye movements cause an increase in sway area, velocity and variability [18]. However, there is limited research to determine these relationships, and there is still discussion on how eye movements affect balance. It is supposed that eye tracking may influence the outcome of balance testing and, therefore, make scientific research or clinical assessment unreliable.

The aim of the study was to investigate whether eye tracking of a point smoothly moving in different directions affects the results of a balance test on stable and foam surfaces in young healthy adults.

The following research hypotheses were stated: (1) eye tracking of a moving point worsens the results of the balance test compared to tests performed by observing a fixed point, (2) diagonal movements of the tracked point cause greater COP sway than horizontal or vertical movements, and (3) more challenging balance test conditions increase the observed changes in COP sway.

2. Materials and methods

Participants

The study was conducted at the Movement Analysis Laboratory at the Medical University of Warsaw between December 2021 and March 2022. Forty-five healthy subjects (32 women and 13 men) aged 19–26 years took part in the study. All participants were students from the Medical University of Warsaw. Due to the fact that this type of analysis was not published before, the required sample size was calculated after recruiting the first 10 participants and it was 30 for the expected power value of 0.95. To get reliable data, the number of participants was increased by 50%. Exclusion criteria for the study included musculoskeletal injuries in the period of six months before the trial, current complaints in the lumbar spine, pelvis or lower limbs, neurological or vestibular balance disorders, as well as visual impairment. All participants agreed to take part in this study by signing the informed consent. Before the examination procedure, participants' height and body weight were measured. Height was measured using a height measurement sticker on the wall. Body weight was tested using a mechanical personal scale (TM-815, TECH-MED, Warsaw, Poland). The characteristics of the study group are presented in Table 1.

Table 1. Characteristics of the study group (mean ± standard deviation)

Study group	Age [years]	Height [cm]	Weight [kg]	BMI [kg/m^2]
N = 45 (32 females, 13 males)	22.22 ± 1.69	172 ± 9	70.04 ± 11.05	23.56 ± 3.24

BMI – Body Mass Index.

Ethics Commission approval

The study protocol was approved by the Bioethics Committee of the Medical University of Warsaw (no. KB/217/2020). The study was conducted according to the ethical guidelines and principles of the Declaration of Helsinki.

Examination procedure

The BIODEX Balance System (Biodex Medical Systems, Inc., Shirley, NY, USA) was used to assess

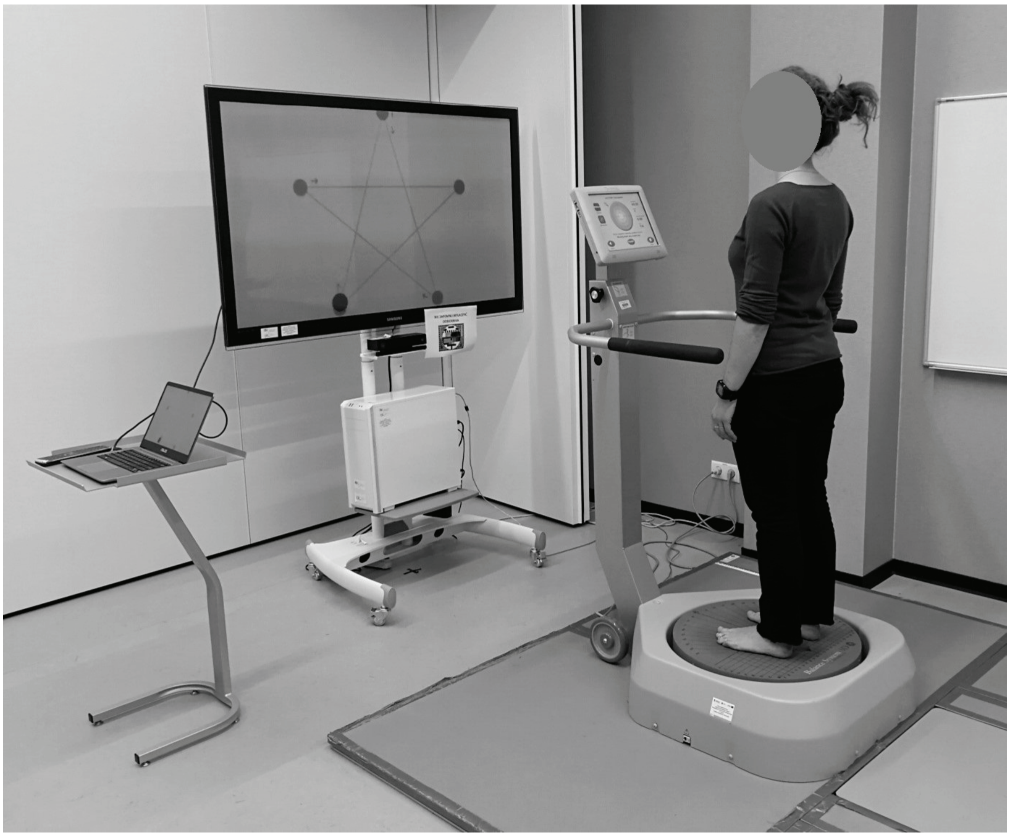
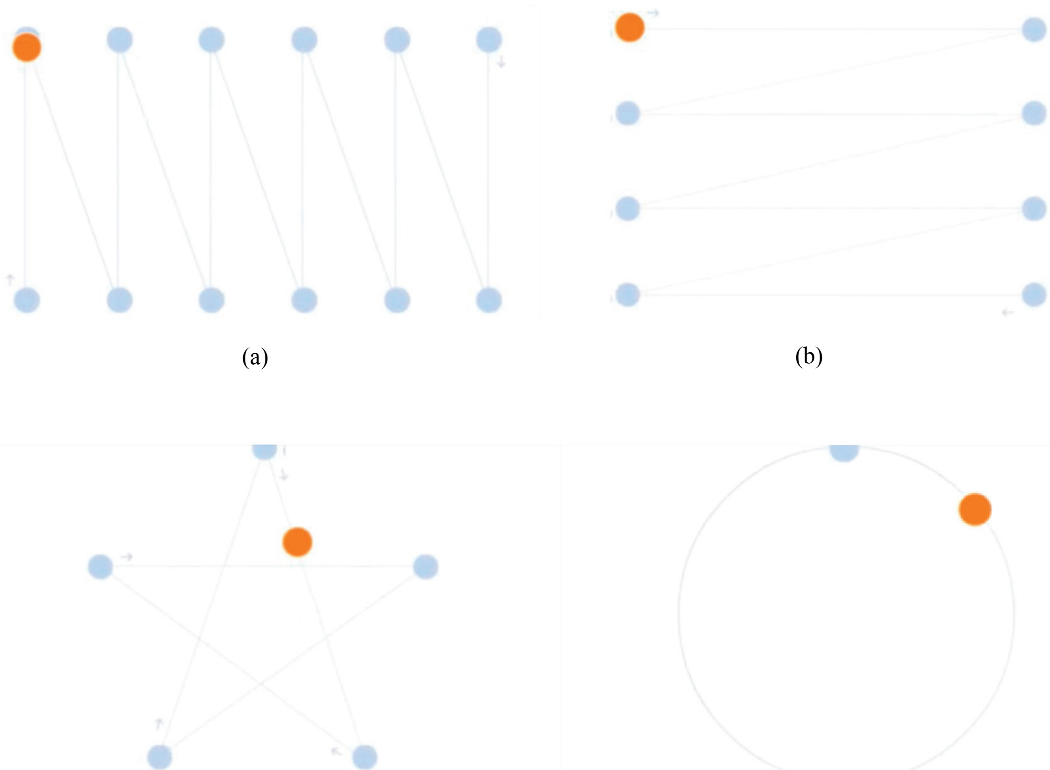


Fig. 1. Hardware setting and participant's position during the test with eye-tracking



(a) (b)

(c) (d)

Fig. 2. The directions of movement in which the eye-tracked point moved:
a) vertically, b) horizontally, c) diagonally in the shape of a star, d) on the circle

body balance. An additional 63″ screen was used to present an eye-tracking task during balance measurement. The distance from the front side of the balance platform to the screen was 2 m (Fig. 1).

The Modified Clinical Sensory Balance Interaction Test (m-CTSIB) was used in the study. Foot position was recorded by obtaining data from the coordinate system of the platform. Each participant repeated measurements in standing on a stable and foam surface in six test conditions, including (1) eyes open, without eye tracking (EO), (2) eyes closed (EC), (3) vertical eye-tracking (VERT_ET), (4) horizontal eye tracking (HOR_ET), (5) star eye tracking (STAR_ET), and (6) circle eye tracking (CIR_ET) (Fig. 2). All trials were performed first on a stable surface (STAB), followed by a foam surface (FOAM), giving 12 measurements for each person. Each trial lasted 30 seconds, with an interval of 10 seconds between trials. All participants performed tests in the same order, described above. For the eye-tracking task, a video of eye-tracking exercises of a moving point was used (Resilience) [27].

The parameter assessed in each measurement was the sway index (SI). The SI represents the standard deviation of the stability index, described as the average position from the center of gravity. Therefore, the higher the SI, the more unstable the person during the test. This parameter was used in our other study [19] and a study by other authors [7].

Statistical analysis

Statistical analysis was performed using PQStat 2021 v. 1.8.2.238 software (PQStat Software, Poznań, Poland). Based on the Shapiro–Wilk test, nonparametric Friedman ANOVA with post-hoc Dunn–Bonferroni test was used. Regression analysis was performed using the multivariate least squares method for Sway Index as the independent variable and the following dependent variables: age, BMI, type of surface, EO/EC condition and shape of the eye-tracking pattern. The selection of the best regression model was based on the Akaike information criterion (AIC). Both types of tests (within-group comparison and regression analysis) were used to confirm or reject all three hypotheses. The p-value was set at 0.05.

3. Results

Friedman ANOVA with Dunn–Bonferroni post-hoc comparisons showed significant differences between EO-STAB and EC-STAB scores ($p = 0.004$). In the comparison of STAB trials, no differences were found between EO and eye tracking of a moving point in all motion directions used in the study. In FOAM trials, significant differences were shown comparing only between CIR_ET and other test conditions ($p < 0.001$). The power for ANOVA comparisons was 0.99. Detailed results for each trial and comparison between STAB and FOAM tests are presented in Table 2.

Regression analysis showed that measurement conditions (eyes open/closed and stable/foam surface), age, and BMI significantly impact test results (Sway Index). There was no impact of eye tracking on test results

Table 2. Results of m-CTSIB test – sway index: mean ± standard deviation; median, quartiles and p-value for Dunn–Bonferroni test

Condition	Stable surface	Foam surface	p-value
Eyes open, without eye tracking, EO	0.68 ± 0.24 Me 0.65 Q1 0.49 Q3 0.86	1.19 ± 0.27 Me 1.12 Q1 1.05 Q3 1.34	<0.0001
Eyes closed, EC	0.88 ± 0.27 Me 0.86 Q1 0.7 Q3 0.99	2.46 ± 0.51 Me 2.32 Q1 2.07 Q3 2.84	<0.0001
Vertical eye-tracking, VERT_ET	0.70 ± 0.22 Me 0.66 Q1 0.53 Q3 0.81	1.22 ± 0.27 Me 1.21 Q1 1 Q3 1.38	<0.0001
Horizontal eye tracking, HOR_ET	0.61 ± 0.23 Me 0.56 Q1 0.46 Q3 0.68	1.25 ± 0.28 Me 1.22 Q1 1.05 Q3 1.48	<0.0001
Star eye tracking, STAR_ET	0.62 ± 0.20 Me 0.57 Q1 0.49 Q3 0.75	1.25 ± 0.28 Me 1.23 Q1 1.11 Q3 1/39	<0.0001
Circle eye tracking, CIR_ET	0.69 ± 0.24 Me 0.64 Q1 0.51 Q3 0.85	1.41 ± 0.36 Me 1.41 Q1 1.18 Q3 1.62	<0.0001

Me – median, Q – quartile.

Table 3. Model of the multi-variation analysis of regression including four variables defining the direction of eye-tracking; non-significant variables are marked with italics

Independent variable: Sway Index $R = 0.815$ $R^2 = 0.664$ $F = 1313.19$ $p < 0.0001$			
Dependent variable	R	SD	p-value
Age	–0.023	0.009	0.0086
BMI	–0.019	0.005	<0.0001
Eyes closed	0.734	0.051	<0.0001
Unstable surface	0.767	0.029	<0.0001
Eye tracking – vertical movement	*0.025*	*0.050*	*0.6254*
Eye tracking – horizontal movement	*–0.006*	*0.050*	*0.9037*
Eye-tracking – star movement	*0.031*	*0.050*	*0.4326*
Eye-tracking – circle movement	0.0112	0.050	0.0271
Const.	1.510	0.242	<0.0001

R – regression coefficient, SD – standard deviation of R, BMI – Body Mass Index.

($p = 0.4326$), although detailed analysis showed a significant impact of tracking a point moving on the circle on test results (Table 3).

4. Discussion

The available literature as well as the present study confirms the importance of visual control, which is present in the open-eye test, for maintaining static body balance, during various disturbing factors. These include any visual disorders (e.g., amblyopia), difficulties in the perception of visual stimuli (e.g., insufficient lighting, optical illusions), as well as testing conditions (eyes open or closed) [4]. Additionally, studies show that COP movements in the AP direction may be related not only to closed eyes, but also to the eyelid closure mechanism itself, or even eyelid tightening while the eyes are closed. Rougier et al. [31] in their study compared COP movements with eyes open in the dark, eyes closed and eyes closed with eyelids tightened. They showed that COP movements are reduced with eyes open in the dark than with eyes closed with eyelids tightened. Also, visual conflict can influence mCTSIB test results, which was shown by Moran and Cochrane [23]. In this study, visual conflict via the vestibular-ocular reflex was induced by moving the head in the horizontal plane as the participants focused to observe a single point displayed on the screen of the Biodex Balance System device. Moran and Cochrane indicated that sway was greater during the visual conflict test than during the open-eye test and looking forward, on both firm and foam surfaces [23].

In the literature, a certain group of studies are those that focus on the effect of eye tracking of a specific single point on the results of postural balance. These studies focus on two types of eye movements: saccades and smooth pursuits. Some studies have shown that saccadic eye movements reduce sway area, the amplitude of the COP displacement, and movements along both the anteroposterior and mediolateral directions in healthy young adults [28], [29], [30]. In contrast, the results of the research using smooth eye movements are not clear [18], [24], [29], [37]. Therefore, in our study, we decided to focus on smooth pursuit eye movements.

Our first hypothesis assumed that eye tracking of a moving point worsens the results of the balance test compared to tests performed by observing a fixed point. However, the results presented in our study indicate that smooth eye movements while performing balance tests in both-leg standing on a stable surface do not affect the test results in young, healthy subjects. In the tests performed on an unstable surface, a difference was only observed in the test with a circular movement of the tracked point. However, results different from ours regarding testing on stable surfaces were reported by Rodriguez et al. [29] and Thomas et al. [37]. The results of Rodriguez et al. [29] showed a reduction in body sway during balance tests during smooth pursuits compared to balance tests performed with gaze fixation on a single point. Thomas et al. [37] studied the effect of computer-generated different visual stimuli on postural sway. The authors showed that, compared to fixating on a stable target, smooth pursuits increased postural sway. Lafleur and Lajoie [18] observed an increase in postural sway with smooth-pursuits movements, which stays in line with Thomas et al. [37], but in opposition to Rodriguez [29]. The reason for the increased postural sway in smooth-pursuits eye movements during eye tracking of a horizontally moving point may be due to subtle head movements, which is also supported by the study of Laurens et al. [20].

Our second hypothesis assumed that diagonal movements of the tracked point increase Sway Index more than horizontal or vertical movements. Most studies [18], [20], [24], [29] evaluated smooth-pursuit eye movements vertically or horizontally. In our study, the tracked object also moved in circular and star-shaped diagonal directions. Our results indicate significant differences only in the test with a circular movement of the tracked point. On the other hand, Kim et al. [17] showed that smooth-pursuit eye movements without head movement impair balance, and the magnitude of the changes was influenced by the direction of eye movement. They used the diagonal movement of the tracking point performed among 40 young healthy subjects who were fitted with a cervical collar to restrict their head movements. Diagonal movements caused more balance impairment than vertical and horizontal movements. It was also observed that postural stability deteriorates and the risk of falling increases as the velocity of the tracked point increases. In our study, even though the tracked point performed a more complex diagonal movement, no similar relationship was noted. This could have been related to the low speed of the moving point in our study. This suggests that the velocity of the moving point should be one of the variables in future studies.

Our third hypothesis assumed that more challenging balance test conditions increase the observed changes in Sway Index. The results of our study may confirm this hypothesis partially. Significant differences were observed in the foam surface test, but only in one of the four trials used – the circular movement of the tracked point. Most studies [17], [18], [29], [37] evaluated smooth-pursuit eye movements and saccadic eye movements in both-leg standing position on a stable surface. In the study of Nakahara et al. [24] each task was performed using both-leg and single-leg standing. They used 4 postural control tasks: without moving visual target, randomly presented visual target, uniform linear visual target and regular enlarged visual target. The results showed that smooth pursuits induce a larger amplitude of COP displacement during single-leg standing than both-leg standing. The authors point out, also referring to other studies [33], [35], [38] that the amplitude of COP displacement is closely related to the difficulty of postural tasks. This is also confirmed by our results. In all the used tests, SI was significantly higher in trials performed on the foam surface. Similar relationships were pointed out by Lafleur and Lajoie [18] explaining that the differences between their results and those of the Rodriguez [29] study may be due to different foot positioning. Rodriguez's study used standing with the feet positioned shoulder-width apart, while Lafleur and Lajoie's study subjects stood in a position with their feet together. The position of the feet can determine the outcome of the trial because standing with feet together or standing on an unstable surface is a more difficult balance task than standing with feet positioned shoulder-width apart. These observations could partly explain the results obtained in our study, especially the fact that differences were observed only in unstable conditions (FOAM test), in which the somatosensory system is more involved. Additionally, the circular eye-tracking task included complex eye movement, more involving the vestibular system than other tested conditions. This type of movement may have been accompanied by small head movements, which also influenced test results.

As the papers show, the results of studies on the effect of eye tracking of a moving point on balance performance vary with each other. The research methodology itself is different, and often not precisely described. Consequently, it is difficult to compare results among themselves. The various conditions of testing: the environment in which the test is performed, the intensity of light in the room, the colour and size of the moving point, as well as the velocity and the direction of the movement, can all affect the results obtained. Also, the position of the person being tested matters (in particular, the feet position), as well as the surface (stable/unstable). These aspects should be taken into account when planning further studies on the effects of eye movements on balance, which are undoubtedly needed to determine the conditions necessary to obtain reliable data. Our research has shown that smooth eye movements are not important for maintaining postural balance. However, available evidence on the various effects of smooth eye movements on balance tests, suggests that eye movements should be avoided when performing the test in a clinical setting. Therefore, instructions for performing balance tests, as well as a description of methods should include precise guidelines for patient positioning and information about eye fixation.

Apart from the defined hypotheses, the analysis of regression showed that age and BMI significantly affect the SI parameter score. Both R coefficients were negative, meaning that older age and higher BMI lowers SI values. Although the results were significant, the range of ages in the study group (19–26) does not allow us to extend the conclusions to significantly older or younger people. On the other hand, other studies do not always confirm the effect of age on COP sway even in comparisons between young and older people [9] and age-related changes in postural sway are controversial [39]. Also, the mean BMI score in the study group (23.56 ± 3.24) indicates that the subjects were in the normal range or only slightly above. However, the results presented by Błaszczyk et al. [5] and Hamilton et al. [14] indicate that BMI can affect balance parameters. However, these studies involved comparing groups with different BMI values according to the WHO classification. Therefore, the results obtained in our study do not allow to draw reliable conclusions regarding the influence of age and BMI on body balance.

A few limitations of this study have to be acknowledged. The study used a test which is relatively easy to perform for young, healthy individuals. Therefore, further research should examine whether a more difficult balance test, such as single-leg standing or increased level of instability, affects the results obtained. In this study, a constant velocity of the eye-tracked point was used, and as the results of the study of Kim et al. [17] have shown, the use of higher velocities of eye-tracked point provokes more changes in postural stability. Thus, future studies should consider different velocities of the moving point. It would also be worthwhile to compare the above-described results to the group with balance impairments.

5. Conclusions

Eye-tracking does not influence the results of balance tests performed on a stable surface. Diagonal movements of the tracking point do not cause more sway than horizontal or vertical movements. However, the circular movement of the tracking point can significantly influence the results of the mCTSIB test in more challenging balance tests involving the somatosensory system, such as tests performed on an unstable surface. Studies should be continued to determine whether eye tracking direction and speed affects the outcome in more difficult balance tests.

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