



INFLUENCE OF LONG-LASTING BALANCING ON UNSTABLE SURFACE ON CHANGES IN BALANCE

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ABSTRACT

Purpose. The goal of this thesis is to test the qualification of changes in balance as the effect of long-lasting balancing on a movable platform alternately in sagittal and frontal planes. It was expected to find answers to the following problems: 1. Does the effort caused by a 10-minute balancing in the given planes and in the given pattern have an influence on dynamic balance parameters? 2. Till which moment are the subjects able to improve their balancing skills in the given planes? 3. Do the possible changes progress in the same way in both planes considered? **Basic procedures.** 28 men aged between 24.3 and 33.8 years took part in this test. Average age of the subjects was 25.2 years. The tests were made on EasyTech Balance Platform. Tests consisted of a trial of balancing in a standing position with feet placed parallel on the platform. The subjects' task was to operate the platform through the right feet pressure to make the same sinusoid line as the pattern was. A ten-minute trial was made alternately in the sagittal and frontal planes. Individual dynamic parameters were recorded each minute of the test. **Main findings.** Significant improvement was noted in the first three minutes of the test. Between the 4th and 7th minutes parameters were relatively stable. The best results were recorded in the 8th minute of the test and this level was kept till the end of the trial. The character of the observed changes was analogous in the case of both planes. **Conclusions.** There was a statistically significant improvement in the dynamic body's stability noted in both planes in the test. Best results were recorded in the 8th minute of the test. The test used in the trial was long enough to establish the borderline between motor learning and the beginning of tiredness. The higher level of stability in the sagittal plane was affirmed in all successive minutes of the trials made.

Key words: coordination motor ability (CMA), body balance, motor learning, fatigue

Introduction

Human motor activity is mostly conditioned by keeping the upright posture, therefore keeping it is considered natural. Balance is only a momentary state of the postural system when the forces acting on the man and their moments counteract each other. Stability is a larger term; it is understood as an ability to return actively to the typical human body posture in space, which was lost either because of the human's motor activity or because of some external forces developed in the interaction with the environment [1, 2].

Body balance is regulated by the nervous system and it depends, to a great extent, on its efficiency. The regulation is based on processing signals arriving from four sensorial entrances: labyrinth, sight organ, proprioceptors and tactile receptors [3]. Signals from all the sensorial entrances constitute a source of information about the body posture and its orientation relative to

the specific frames of reference: internal and external. The central body representation is being formed on the basis of signals from muscle, tendon, joint and skin receptors. These receptors transmit to the brain information about the positions of different parts of the body in relation to each other and about their movements; moreover, the receptors send to the executive organs (muscles) feedback signals which control balance keeping [2, 4]. Deviations from the intended state initiate a stimulation whose aim is to introduce the right muscle correction [3, 4]. Due to the muscle contractions, forces indispensable to compensate all the disturbing factors are developed [5, 6]. Limiting any of these control mechanisms can influence the overall efficiency of the balance system.

When there are no sudden and unpredictable external disturbances, the main mechanisms of posture correction which make balance keeping possible are anticipative and corrective actions. Recovering balance is a sequential process. After the sensorial systems detect the kind, size and direction of the disturbance, an adequate reaction is adopted to recover balance. The reaction has to be set in motion and completed in a strictly limited time [2].

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Regulation of the body balance while any movements are being performed requires anticipative adjustment. However, maintaining the body posture is, first of all, an effect of the functioning of correction adjustment mechanisms [2, 3]. Anticipative adjustments do not exclude the possibility of a feedback position adjustment occurring in a further phase of a movement, which is a reaction to stimuli coming from proprioceptors informing about the occurrence of disturbing factors [7, 8]. Probably, both position correction mechanisms can act simultaneously, which depends on the kind of the initial signal indicating its constant or momentary disturbance occurrence [9, 10]. One mechanism introduces constant corrections of the position by making use of the close feedback loop. The other one is responsible for adjusting a posture during its sudden and short-lasting disturbances [11].

In a standing position, in order to keep or recover balance it is possible to apply two strategies depending on the degree of its disturbance: an ankle or a hip joint [12–14]. One strategy refers to a minor balance disturbance and it is initiated by a contraction of ankle muscles. The other one refers to bigger disturbances and it is initiated by an activity of thigh and trunk muscles, and then moves downwards to other leg muscles [14–16].

Stability is, undoubtedly, an important physiological reaction, which is influenced by numerous factors including tiredness. However, its importance has not been examined enough. Few studies deal with types of tiredness, its influence on stability, and a response of the control system to disturbances of the internal environment [17]. According to many researchers, tiredness influences balance negatively and may cause injuries or wounds [18, 19]. The influence on the change in a balance level caused by aerobic efforts performed in the form of long-distance runs was studied by Nardone et al. [20, 21]. Similar research has been carried out by Pendergrass et al. [22]. Lepers et al. [23] dosed the effort of the subjects applying an intensive 25-minute walk or exercise bike ride (cycloergometer). It was stated that both tiredness [20, 21, 24] and hyperventilation [25] caused by an effort can have a negative influence on stability depending on its kind, intensity and duration. It was noted that running weakens the balance parameters much more than marching or cycling [26, 27]. Short-lasting, suddenly done intensive work has a more negative impact on balance than an effort of an aerobic character, i.e. an exercise done within a longer period of time and of moderate intensity [23].

Moreover, sports disciplines in which even small changes in stability after an effort influence negatively the performance were defined, for example: biathlon,

gymnastics, figure skating, rock-and-roll, basketball, tennis, windsurfing [28–30]. Therefore, the assessment of stability is considered an important element in functional diagnostics of persons practising these sports.

The influence of anaerobic efforts on the level of balance was studied by Waśkiewicz [17]. However, he has not received an unequivocal answer as to whether they have a positive or negative influence on balance. Also, the influence of local tiredness of feet muscles on changes in the sagittal amplitude of movements has been studied [31]. Zemková et al. [30] have done interesting research based on EquiTest, where they have compared the influence of tiredness caused by an intensive effort on an exercise bike on the level of balance in the static and dynamic conditions. The experiment has not shown any differences in the balance levels on the stable surface measured before and after the effort. Whereas, in the dynamic conditions the obtained results indicated a significant drop in the balance level. Unlike the well-known, commonly used method of static posturography, presently, in literature there are few reports concerning the influence of such exercises on balance on the unstable surface [23, 30].

Mere keeping a stable position, especially in the dynamic conditions, involves a significant effort and related to it progressing tiredness. If, additionally, it is connected to the performance of an imposed motor task, tiredness should increase more quickly. Thus, the aim of this work is to try to define changes in balance in the condition of long-lasting balancing on a movable platform examined separately in the frontal plane and the sagittal one. Answers to the following questions were expected to be found:

1. Does the effort caused by a 10-minute balancing in given conditions have any influence on changes in the balance parameters?
2. Till which moment of the test are the subjects able to improve their skills of balancing in each movement plane?
3. Do the possible changes progress in the same way in both planes examined?

Material and methods

Subjects

Twenty eight male students of the University School of Physical Education in Kraków took part in the experiment. None of the people invited for the test complained of balance disturbances and had had any injuries which could have influenced the results of the measurements. All the participants were volunteers.

The subjects' average age was 25.2 years and ranged from 24.3 to 33.8. Their average height was 180.5 cm and their average weight 77.7 kg (BMI 23.8).

Research apparatus

In order to examine the dynamic balance, a balancing platform *Libra* of an Italian company *EasyTech* was used. The measuring station consisted of: a platform with USB interface and a notebook with a 15" screen connected to it. The device has three possible settings of the balance base diameter: 10, 25 and 40 cm. The software provides for application of one of the four kinds of pattern lines for the trial course: straight line, sinusoid, square wave and triangular wave. Trials can be conducted in standing, sitting and lying positions. In the standing position it is possible to place feet: parallel in the frontal and sagittal planes, as well as at a 45° angle. The operator has the possibility of setting amplitude and frequency of the lines emitted on the screen, as well as the possibility of using an appropriate degree of difficulty corresponding to the angular sway range. Exceeding the range of the difficulty degree is shown on the screen as two parallel lines placed on each side of the pattern. Each time one goes beyond the borderline, an acoustic signal turns on. In this experiment the pattern line adopted was a sinusoid of amplitude 5° and frequency 10 cycles/min. The balance curve was $r = 40$ cm and the 6th difficulty degree (deviation from the pattern line $\pm 5^\circ$) applied. These parameters were set taking into consideration the previous tests conducted on the platform *Libra* [32].

The final result of the measurement is the mean calculated (within the range from 0 to 100) on the basis of the eight examined parameters (the value 100 means the poorest balance, 0 means the best). The parameters

are: **total area** – contained between the line of the movement course obtained by the subject, which is the function of the angular sway and time (°s), and the model sinusoid (all the parameters are measured separately for deviations to the left and to the right in the frontal plane, as well as forward/backward deviations in the sagittal plane); **external area** – comprised between the line of the movement course obtained by the subject and the line of the given difficulty degree (°s); **external time** – the total period of time the subject spends outside the area of the given degree of difficulty (s) and **reaction time** – the longest time the subject spends outside the area of the given degree of difficulty (s). The subject's better stability is characterised by the lowest possible values of all the parameters.

Research procedures

Measurements were taken in two trials, separately for the frontal plane and the sagittal one. Each trial was preceded by a 60-second warm-up in the same settings as in the real trial. The test lasted 10 minutes for each movement plane. The first trial was conducted in the frontal plane, whereas the trial in the sagittal plane was held the day after to avoid cumulating tiredness. The values of the trial parameters were recorded after each minute of the test.

The subject was standing barefoot on the platform, in a stance with the feet placed apart at hips' width and parallel to each other. During the trial the subject was watching his trial's graph on the monitor placed at his eye level and at a distance of 1 meter, which served as feedback. The subject's task was to move the platform by pressing it with his feet in such a way that the line drawn on the computer screen was as close as possible to the pattern sinusoid (coincided with it). During the

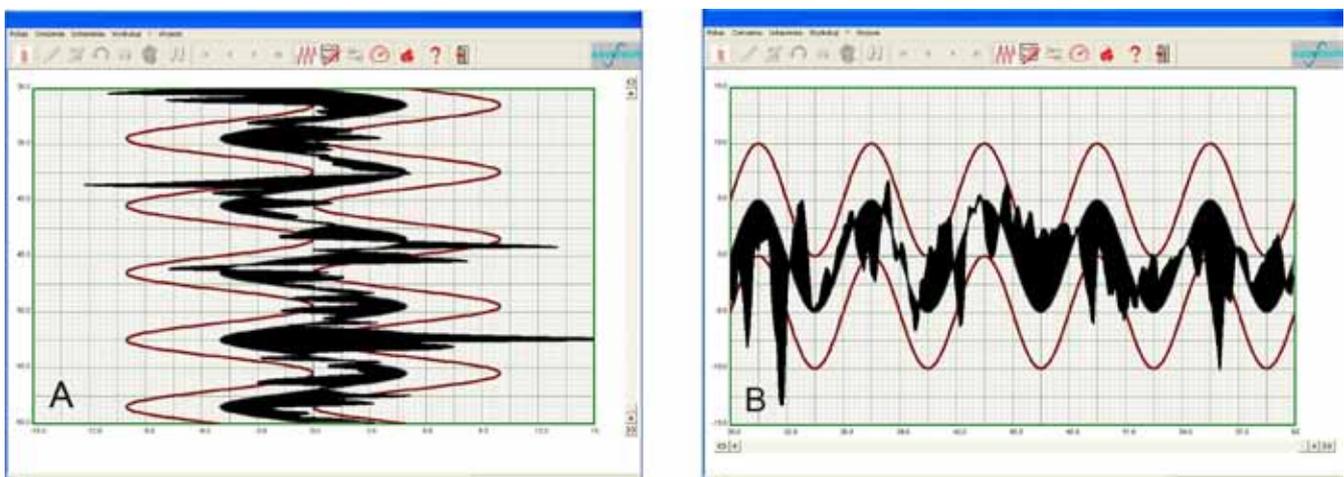


Figure 1. An example of a graph of the trial's course. A – frontal plane; B – sagittal plane

trials in the frontal plane, the graph moved vertically from top to bottom, whereas in the sagittal plane the graph moved horizontally from left to right (Fig. 1).

Data analysis

First, the results were worked out by means of generally used methods of descriptive statistics. Basic numerical characteristics of the tested variables were determined, i.e. arithmetic mean (\bar{x}) and standard deviation (SD).

Due to the fact that it was impossible to obtain the normal layout for all the analysed variables and confirm them by Shapiro-Wilk test, in further analysis non-parametric tests were used.

In order to show the significance of the differences between successive measurements on the same movement plane, Friedman test from ANOVA group was applied.

Differences between the results in each movement plane in consecutive minutes of the trial were verified by Wilcoxon's test. The difference was considered statistically significant if the value of the significance level was $p < 0.05$. Calculations were done using the program Statistica 7.0.

In order to present the direction of the observed

changes graphically, the results of the trials in the sagittal plane compared to those in the frontal plane were standardized according to the pattern:

$$SI = \frac{\bar{X}_{sagittal-pl.} - \bar{X}_{frontal-pl.}}{S_{sagittal-pl.}}$$

- SI – standardized index,
 $\bar{X}_{sagittal-pl.}$ – arithmetic mean of the results of a given balance parameter in the sagittal plane,
 $\bar{X}_{frontal-pl.}$ – arithmetic mean of the results of a given balance parameter in the frontal plane,
 $S_{frontal-pl.}$ – standard deviation of the results of a given parameter in the frontal plane.

Results

In the group examined, results of some chosen balance parameters obtained in the platform during a 10-minute balancing, considered individually for each movement plane, were analysed. Basic descriptive statistics of the obtained results are presented in Table 1.

The most representative variables, which reflect the point why the work was undertaken and the research

Table 1. Descriptive statistics of the results obtained in the dynamic balance test in the consecutive minutes of the trial in the frontal and sagittal planes

Parameters	Frontal plane ($n = 28$)										
	stat.	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min	9 min	10 min
Stability index	\bar{x}	10.10	9.44	9.09	8.57	9.08	8.14	8.53	7.50	7.71	7.44
	SD	2.77	2.77	2.48	2.70	3.09	2.26	2.58	2.65	2.28	2.10
Total area R + L ($^{\circ}$ s)	\bar{x}	186.67	176.38	173.00	166.56	170.38	158.06	162.99	149.88	152.74	150.42
	SD	32.23	32.02	29.96	33.88	36.79	29.23	32.92	33.81	29.00	27.53
External area R + L ($^{\circ}$ s)	\bar{x}	20.23	17.50	16.16	13.85	18.03	12.90	15.20	10.90	11.52	10.39
	SD	14.37	12.89	11.14	11.53	14.62	8.39	11.41	10.60	9.00	8.11
External time R + L (s)	\bar{x}	10.48	9.48	8.77	8.03	8.93	7.56	7.97	6.48	6.84	6.31
	SD	5.05	4.93	4.39	4.64	5.26	3.99	4.23	4.41	3.80	3.65
	Sagittal plane ($n = 28$)										
Stability index	\bar{x}	8.51	7.76	7.05	7.05	7.24	7.15	6.50	6.05	6.51	6.05
	SD	2.53	2.44	2.41	2.41	2.14	2.11	2.10	1.77	2.13	1.88
Total area F + B ($^{\circ}$ s)	\bar{x}	164.40	154.21	144.10	143.70	146.15	144.53	136.75	130.24	136.66	129.49
	SD	30.06	31.30	31.24	31.50	28.42	27.03	28.04	25.80	27.95	25.57
External area F + B ($^{\circ}$ s)	\bar{x}	13.87	12.16	9.14	9.13	9.72	9.87	7.69	6.49	8.06	6.23
	SD	11.26	10.65	9.11	8.42	8.41	8.68	7.71	6.95	8.33	6.25
External time F + B (s)	\bar{x}	8.07	6.79	5.80	5.76	6.02	6.03	4.77	4.16	4.84	4.25
	SD	4.55	4.14	4.18	4.24	3.60	3.74	3.45	2.54	3.48	3.17

R, L – right, left side; F, B – front, back

questions asked, turned out to be: **final result, combined total area** – defining the range of lateral sways in the frontal plane (total area R + L) and forward-backward sways in the sagittal plane (total area F + B), **combined external area** that extends beyond the area delineated by the difficulty degree of the test (area R + L and F + B) – defining the precision of adjusting movements made and the total time the subject spends beyond the difficulty area (external time R + L and F + B).

In order to verify if the observed differences between the measurements taken at one minute intervals are statistically significant, a non-parametric statistical test for multiple dependent variables of Friedman ANOVA group was used (Tab. 2).

In all the cases statistical significance of the observed differences is unquestioned. In the case of both planes they are significant – over 99% probability ($p < 0.0001$). Particularly significant changes were stated in the case

Table 2. Significance of the changes in parameters of dynamic balance achieved by the subjects in the course of a 10-minute balancing trial conducted in the frontal and sagittal planes

Plane	Parameter	Friedman ANOVA test and Kendall's τ			
		<i>n</i>	χ^2	<i>p</i>	τ
Frontal	stability index	28	72.57	0.00000	0.29
	total area R + L	28	82.27	0.00000	0.33
	external area R + L	28	35.93	0.00004	0.14
	external time R + L	28	57.35	0.00000	0.23
Sagittal	stability index	28	73.62	0.00000	0.29
	total area F + B	28	83.13	0.00000	0.33
	external area F + B	28	40.83	0.00000	0.16
	external time F + B	28	55.83	0.00000	0.22

statistically essential values were distinguished in bold type R, L – right, left side; F, B – front, back; *p* – significance level; χ^2 – chi-squared statistics; τ – Kendall's coefficient of concordance

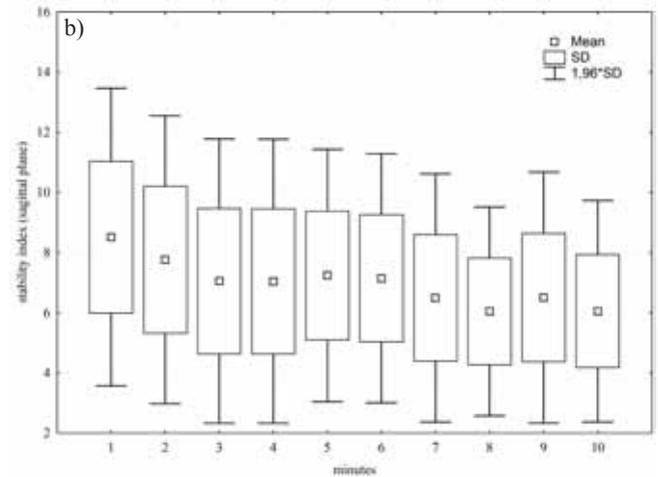
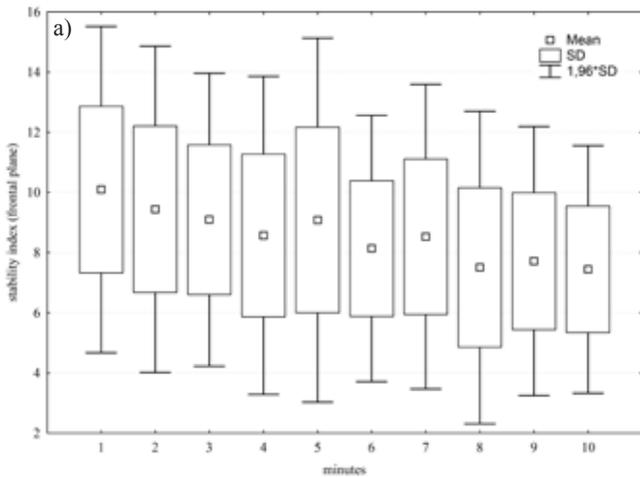


Figure 2. Changes in the arithmetic mean of the final result in a balancing trial on Libra platform in the consecutive minutes of the test: a) frontal plane; b) sagittal plane

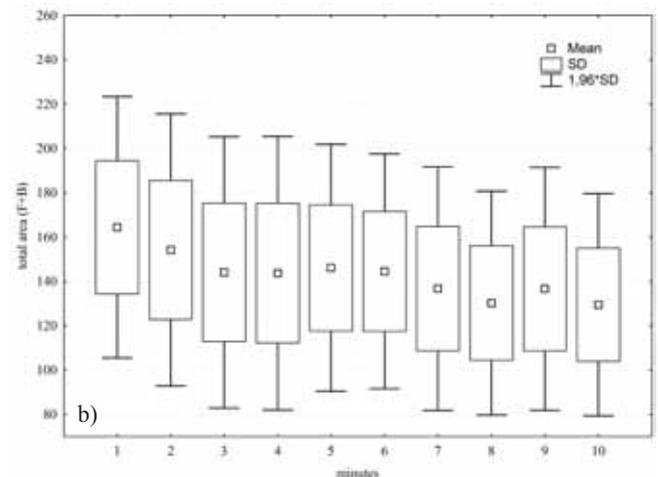
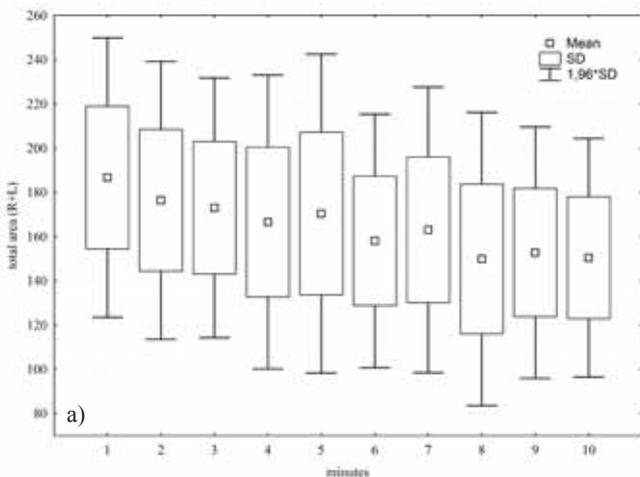


Figure 3. Changes in the arithmetic mean of total area (°s) in balancing trial on Libra platform in the consecutive minutes of the test: a) frontal plane; b) sagittal plane

of the basic index of the conducted test (independent of the difficulty degree) – total area. The values of Kendall's conformity coefficient τ exceeded 0.3, and in the case of the statistics coefficient χ^2 exceeded 80.

Comparing the Friedman test results to the raw data, it was stated that there was a significant improvement

in balance during the 10-minute balancing trial. In that time the total area in the frontal plane decreased by 19%, while in the sagittal one by 21%.

However, the changes did not proceed in a linear way, but in a similar way in all the parameters analysed (Tab. 1, Fig. 2 and 3). An essential improvement was

Table 3. Significance of changes in the consecutive minutes of the trial in relation to the dynamic balance parameters achieved by the subjects in the frontal and sagittal planes

Parameters (variables) compared		Wilcoxon's test			
		<i>n</i>	<i>T</i>	<i>Z</i>	<i>p</i>
1 minute	stability index (frontal) & stability index (sagittal)	28	73.50	2.9489	0.0032
	total area R + L & total area F + B	28	51.00	3.4613	0.0005
	external area R + L & external area F + B	28	92.00	2.5276	0.0115
	external time R + L & external time F + B	28	96.50	2.4252	0.0153
2 minute	stability index (frontal) & stability index (sagittal)	28	68.50	3.0628	0.0022
	total area R + L & total area F + B	28	56.00	3.3474	0.0008
	external area R + L & external area F + B	28	100.00	2.3455	0.0190
	external time R + L & external time F + B	28	81.50	2.7667	0.0057
3 minute	stability index (frontal) & stability index (sagittal)	28	38.00	3.6278	0.0003
	total area R + L & total area F + B	28	30.50	3.9281	0.0001
	external area R + L & external area F + B	28	63.00	3.0271	0.0025
	external time R + L & external time F + B	28	64.50	3.1538	0.0016
4 minute	stability index (frontal) & stability index (sagittal)	28	84.50	2.5106	0.0121
	total area R + L & total area F + B	28	68.00	3.0741	0.0021
	external area R + L & external area F + B	28	121.50	1.8559	0.0635
	external time R + L & external time F + B	28	91.00	2.3544	0.0186
5 minute	stability index (frontal) & stability index (sagittal)	28	72.00	2.9831	0.0029
	total area R + L & total area F + B	28	62.00	3.2108	0.0013
	external area R + L & external area F + B	28	58.00	3.3019	0.0010
	external time R + L & external time F + B	28	80.00	2.8009	0.0051
6 minute	stability index (frontal) & stability index (sagittal)	28	110.50	2.1064	0.0352
	total area R + L & total area F + B	28	104.00	2.2544	0.0242
	external area R + L & external area F + B	28	123.00	1.8217	0.0685
	external time R + L & external time F + B	28	118.00	1.9356	0.0529
7 minute	stability index (frontal) & stability index (sagittal)	28	34.00	3.8484	0.0001
	total area R + L & total area F + B	28	33.00	3.8711	0.0001
	external area R + L & external area F + B	28	35.00	3.8256	0.0001
	external time R + L & external time F + B	28	38.50	3.7459	0.0002
8 minute	stability index (frontal) & stability index (sagittal)	28	64.00	2.8319	0.0046
	total area R + L & total area F + B	28	81.00	2.7781	0.0055
	external area R + L & external area F + B	28	98.50	2.3796	0.0173
	external time R + L & external time F + B	28	88.00	2.6187	0.0088
9 minute	stability index (frontal) & stability index (sagittal)	28	108.00	2.1633	0.0305
	total area R + L & total area F + B	28	104.00	2.2544	0.0242
	external area R + L & external area F + B	28	125.50	1.7648	0.0776
	external time R + L & external time F + B	28	117.00	1.9583	0.0502
10 minute	stability index (frontal) & stability index (sagittal)	28	37.00	3.5176	0.0004
	total area R + L & total area F + B	28	29.00	3.9622	0.0001
	external area R + L & external area F + B	28	90.00	2.5732	0.0101
	external time R + L & external time F + B	28	76.00	2.8920	0.0038

statistically essential values were distinguished in bold type

R, L – side right, left; F, B – front, back; *p* – significance level; *T* – Wilcoxon's test value $n \leq 25$; *Z* – Wilcoxon's test value $n > 25$

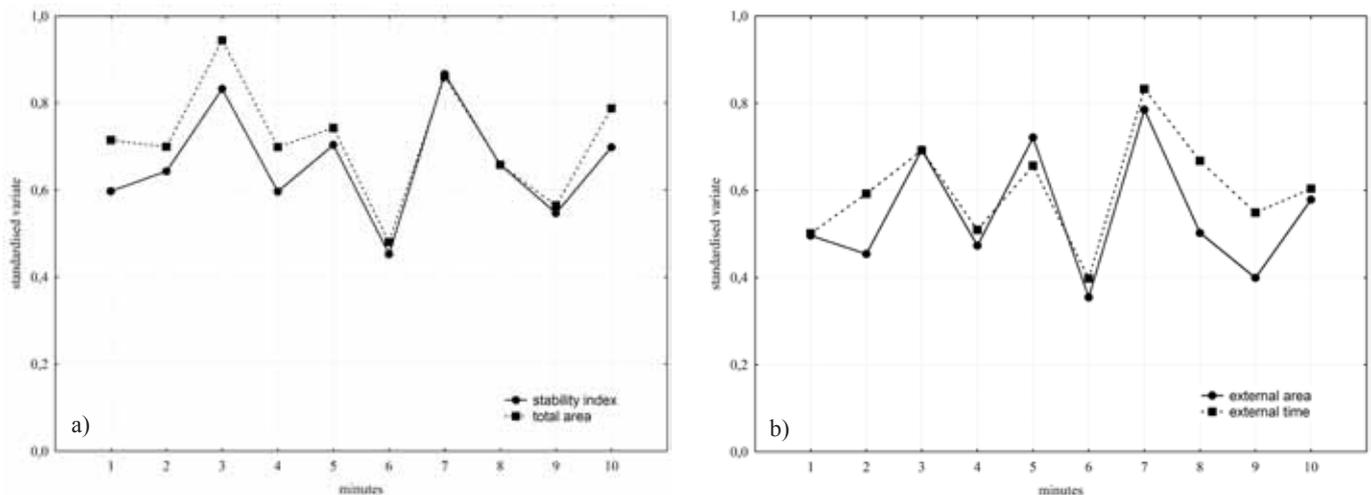


Figure 4. Standardized values of balance parameters in the trial of balancing on Libra platform in the consecutive minutes of the test (standardization of results in the sagittal plane in comparison to the frontal one): a) performance and total area; b) external area and external time

observed in the first three minutes of the trial. Between the 4th and 7th minutes the balance parameters underwent a relative stabilization. The subjects achieved the best results in the 8th minute of the test and kept this level till the end. The character of the changes was the same in both movement planes.

In order to compare the results obtained by the subject in the frontal and sagittal planes, Wilcoxon's test of succession was used. The significance of differences was defined in each minute of the test. The results obtained in a comparative analysis are shown in Table 3.

In each minute of the test the diversity between the test results in the frontal plane and in the sagittal one are statistically significant. The few cases where such difference was not noticed concern the parameters dependent on the difficulty degree of the test. In the case of statistics Z , the highest degree of diversity concerns almost exclusively the total area.

Comparing Wilcoxon's test to the raw data, it was stated that in the examined group there was a higher level of dynamic balance in the sagittal plane. These relations undergo minor oscillations during the trial. In the normalized values, the advantage of the sagittal plane fluctuates between 0.4 and 0.9 s (Fig. 4).

Discussion

The reason why the present study was undertaken was the result of the previous research done by the same authors [32], where the subjects balanced on the platform alternately in the frontal plane and in the sagittal one with a 20-second break between the trials. The test applied in that experiment turned out to be too short (to-

tally 10 minutes, alternately 5 minutes for each plane) to determine the borderline between motor learning and initial symptoms of tiredness. That is why, in the present study, the measurements have been taken during a continuous 10-minute trial separate for each plane.

The results of the present study, like those of the previous one, have not shown unequivocally a negative influence of the effort caused by long-lasting balancing on the platform on dynamic balance in the subjects. On the contrary, during a 10-minute balancing trial significant improvements in the performances have been noted. However, now, the increase has not been regular. Its 56% in the frontal plane and almost 60% in the sagittal plane occurred in the first three minutes of the trial. Between the 4th and 7th minutes it did not exceed 20%. The subjects achieved the best results in the 8th minute of the test and kept them till the end. The character of the observed changes has been the same in reference to both movement planes.

The reason of such a significant improvement in the first minutes of the test can be explained by the strategy of the balance keeping adopted by the subjects. Standing on the platform and having difficulty in keeping balance, in almost all the cases, they were making active movements of the trunk. It is a typical way of regulating balance in the strategy of the hip joint when a person, keeping balance by making dynamic movements of different parts of the body, makes use of the resistance of moments of inertia to move other parts of the body. In this strategy the person making movements in the hip joints, while the lower part of the body rests on the surface, becomes support for the movements performed by the upper part of the body [33].

In the successive minutes of the trial, trunk movements were decreasing, which suggests a change of strategy. As a result of the trunk stiffness, the balance control was held by the ankle area. The new strategy allowed the subjects to control balance precisely stabilizing its level until the 8th minute of the test.

Also, it should be taken into consideration that both the change of strategy and the further improvement in the performance could have been the effect of motor learning. The process continued until the 8th minute and then, because of the fatigue, the subjects did not reach their best performances. Finishing the trial they complained about fatigue they felt in lower limbs. A similar effect of learning how to balance has been achieved by Juras [4], based on the blocked practice method which consists of six series of five 30-second repetitions with 15-second intervals between them and 2-minute rests between the series.

In the conditions of the balance measurement on stabilographic platforms, a wider range of sways and higher oscillation frequency of the centre of gravity projection onto the base is observed in the sagittal plane. Stability in the static conditions, in a stance in the frontal plane is much better [13, 16], which is mainly related to the anatomic structure of the feet and the adopted strategy of balance keeping. In the condition of the movable surface the relations discussed are not that explicit.

In the presented study it was stated that there was a higher level of balance parameters in the sagittal plane in all the successive minutes of the conducted trials. The mutual relations did not undergo significant fluctuations and stayed within the limits of the standard deviation, i.e. 0.5. Similar results in the dynamic conditions have been obtained by Zemková et al. [30]. In their case, measurements were taken before and after the effort of an anaerobic character. The authors did not find differences between the movement planes in the static conditions. In their opinion, evaluation of sways in the dynamic conditions can be considered to be more sensible and suitable, especially for sports' needs. Moreover, a dynamic posturography provides additional useful information concerning preferences in choosing strategies of keeping balance and ability to use the information coming from vestibular, sensorial and visual entrances in order to keep balance.

Lundin et al. [31] claim that balance in the sagittal plane is controlled by the ankle strategy. A decrease in preferences of the ankle strategy in this movement plane can be caused by tiredness [14], which, in consequence, can result in deterioration in stability. However, in some works, like in our research, it was observed that there was a more considerable increase in sways after an

effort in the frontal plane than in the sagittal one. It took place while aiming a rifle after a simulation of a ski race [28] or after certain tasks in acrobatic sports [29]. Kuczyński and Wieloch [34] obtained similar results studying an influence of quickened breathing on postural stability. Quickened breathing had little influence on deterioration in stability in the sagittal plane in comparison to the frontal one. Our own measurements and the quoted examples of other authors' studies, performed both on stabilographic platforms and in dynamic conditions, may suggest a lower stability (caused by an effort put in keeping the upright posture) in the frontal plane. To state explicitly such correlations requires further research.

Conclusions

The influence of the effort caused by balancing on the movable platform on the male subjects' stability is not unequivocal. In the first minutes there was a considerable improvement in stability in both planes, only after the 8th minute the first symptoms of adverse effect of tiredness on the balance level appeared. The improvement in stability, observed regularly from the 1st to 8th minute of the trial duration, could have had a relationship with the change of strategy of balance keeping and, related to it, motor learning.

The fatigue caused by a 10-minute balancing did not result in a visible deterioration in the analysed parameters, but only their stabilization at a much higher level than at the moment when the test started. The applied test does not answer the question of after how long the effort related to a performance of an equivalent task will lead to such fatigue that the subjects' stability will deteriorate significantly. However, the test appeared to be long enough to delineate a borderline of motor learning and appearance of the first symptoms of tiredness.

The direction of the changes during the whole experiment was very close in both analysed movement planes. Nevertheless, better results of stability were noted in the case of the sagittal plane.

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