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THE EFFECT OF MAXIMAL EXERCISE ON STATIC AND DYNAMIC BALANCE IN ATHLETES AND NON-ATHLETES

Erika Zemková[1(A,B,C,D,E,F)], Jukka Viitasalo[2(A,G)], Heikki Hannola[3(A,B,G)], Minna Blomqvist[2(A)], Niilo Konttinen[2(A)], Kaisu Mononen[2(A)]

[1]Faculty of Physical Education and Sport, Comenius University, Bratislava, Slovakia
[2]KIHU - Research Institute for Olympic Sports, Jyväskylä, Finland
[3]School of Sports and Leisure, Polytechnic Rovaniemi, Finland

Abstract

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Introduction: Though the effect of different forms of exercise on static balance has been studied, there are only scarce reports concerning its influence on dynamic balance.

Aim of the study: The study deals with postural sway response to maximal exercise.

Methods: A group of 30 athletes and 10 non-athletes underwent in random order in different days balance tests prior to and after maximal exercise bout on the cycle ergometer. Pre-exercise protocol comprised of standard SOT and HS SOT conditions based on the EquiTest dynamic posturography system. In the SOT, during the first three conditions with eyes open, eyes closed, and sway-referenced vision the support surface was fixed and during the same next three conditions the support surface was sway-referenced. In the HS SOT, support surface was either fixed or sway-referenced while subject´s eyes were closed and their head was moving in roll and pitch planes. After exercise only selected conditions were repeated, two static with subjects eyes open and closed and two dynamic with their eyes closed and sway-referenced vision.

Results: There were no significant differences in the equilibrium and strategy scores after exercise as compared to baseline neither with eyes open nor eyes closed while standing on stable platform. On the other hand, in dynamic conditions these values were significantly lower than prior to exercise as with eyes closed as with sway-referenced vision. In addition, sensory analysis revealed that vestibular system is more affected by exercise than somatosensory one. Such an impairment of postural stability after maximal exercise is very probably due to increased ventilation as a consequence of respiratory compensation of lactate induced metabolic acidosis.

Conclusion: In sports dependent on post-exercise postural stability such a metabolic response to exercise has to be taken in account since it seems that this factor plays an important role in maintenance of balance.

Key words: *EquiTest dynamic posturography system, maximal exercise, Sensory Organization Test (SOT) and Head Shake SOT, sway variables*

Introduction

Maintenance of balance involves a complex interaction between sensory organs, central processing, and motor elements. Impairment any of these control mechanisms may influence the overall output of the postural system.

It is known that fatigue (1-3) and hyperventilation (4) induced by exercise have such a detrimental effect on postural stability depending on its type, intensity and duration. Running has been reported to impair the parameters of balance more profoundly than walking and cycling (5,6), short-term abruptly instituted maximal exercise more than longer stepwise exercise with lower contribution of anaerobic glycolysis (7), and longer exercise of moderate intensity more than shorter one of identical intensity (8).

Experience proved that in some sports, such as biathlon (9), gymnastics (10), figure skating, rockenroll (11), basketball (12), tennis (13), windsurfing (14) or sailing (15) even small changes in post-exercise postural stability adversely affect performance. Assessment of postural sway response to exercise is therefore considered as an important part of functional diagnostics of these athletes. However, contrary to well-known and frequently used static posturography for this purpose, in current literature there are only scarce reports (16) concerning the effect of exercise on dynamic balance.

Sensory Organisation Test (SOT) and Head Shake SOT (HS SOT) based on the EquiTest posturography system are used for the laboratory assessment of this ability. In the SOT, subjects are exposed to series of increasingly challenging conditions in which orientation information from the support surface, the visual surround, or both are systematically disturbed by referencing their movements to the subject's body sway (17). In the HS SOT subjects perform rhythmic motions of the head while their eyes are closed and support surface is either fixed or sway-referenced (18).

As evaluation of postural stability in such conditions provide more information about muscle coordination, synergies, and strategies (19) in comparison with currently used static posturography systems, would be useful to ascertain an acute response of these balance control mechanisms to exercice.

Therefore the aim of the study was to compare sway variables of the SOT and HS SOT prior to and after maximal exercise in athletes and non-athletes.

Materials and Methods

Subjects

A group of 30 athletes (mean age 22.9 ± 2.0 years, height 175.7 ± 13.0 cm, and weight 70.7 ± 9.8 kg) and 10 non-athletes (mean age 22.0 ± 3.7 years, height 172.2 ± 9.8 cm, and weight 67.6 ± 6.9 kg) volunteered to participate in the study. All of them were informed of the procedures and of the main purpose of the study.

They completed questionnaire providing information on their physical activity, health status, history of neurological and musculoskeletal disorders or injury, and self-perceived balance ability. No subject reported a history of diseases known to affect the central or peripheral nervous system and the locomotor apparatus, they had normal or corrected-to-normal vision, no reduced hearing, and no subjectively experienced problems of maintaining of balance.

Dynamic posturography

Sway variables were registered by means of the EquiTest computerized dynamic posturography system (NeuroCom International, Inc., Clackamas, Oregon 2000). The system is consisted of a computer controlled, motor driven dual foot plate capable of both rotational and translational movements, and a visual surround capable of rotational movements about an axis collinear with the subject´s ankles. Force traducers located beneath the dual footplate are used to monitor and record the subject´s weight distribution and reactions torques during testing.

The standardized Sensory Organization Test (SOT) and Head Shake Sensory Organization Test (HS SOT) available on the EquiTest system were used in the present study.

The SOT measures how well the subject maintains equilibrium under six sensory conditions. During the first three conditions the support surface is fixed relative to earth horizontal. During the next three conditions the support surface is moved proportional to the subject´s antero-posterior body sway. The three visual conditions are repeated in sequence, the first and fourth with eyes open and fixed visual surround, the second and fifth with eyes closed, and the third and sixth with sway-referenced vision.

The HS SOT identifies the subject´s use of vestibular inputs for balance while actively moving the head in yaw, pitch, or roll movement axes. To isolate the effect of proprioceptive and vestibular inputs on head balance interactions, HS SOT eyes closed trials are repeated under fixed and sway-referenced support surface conditions.

The program analyses up to three 20 seconds trials per test condition sway variables, such as the equilibrium score, strategy score, and sensory ratio.

The equilibrium score quantifies how well the subject's sway remains within the expected angular limits of stability during each SOT condition. The following formula is used to calculate the equilibrium score:

$$\text{Equilibrium score} = \frac{12.5° - (\theta\text{max} - \theta\text{min})}{12.5°} \cdot 100$$

where 12.5 degrees is the theoretical limit of the antero-posterior sway angle range, θmax is maximum sway angle (degrees), and θmin is minimum sway angle (degrees). Subjects exhibiting little sway achieve equilibrium scores near 100, while those approaching their limits of stability scores are near zero.

The composite equilibrium score, the weighted average of the scores of all sensory conditions, characterizes the overall level of performance and is useful in documenting progress over time. The composite equilibrium score is calculated by a) independently averaging the scores for conditions 1 and 2; b) adding these two scores to the equilibrium scores from each trial of sensory conditions 3, 4, 5, and 6; and c) dividing that sum by the total number of trials. The highest possible score is 100.

The strategy score quantifies the ankle and hip movements the subject uses to maintain equilibrium according to the following formula:

$$\text{Movement strategy} = \frac{1 - (\text{Shmax} - \text{Shmin})}{25} \cdot 100$$

where 25 lbs is the difference measured between the greatest shear force (Shmax) and the lowest shear force (Shmin) generated by a test group of normal subjects who used only hip sway balance on a narrow beam. A score near 100 indicates that the subject predominately uses ankle strategy to maintain equilibrium, while a score near 0 represents hip strategy.

The sensory analysis ratios are used in conjunction with the individual equilibrium scores to identify impairments of individual sensory systems. The sensory ratios are computed from the average equilibrium scores obtained on specific pairs of sensory test conditions, as follows (Tab. 1):

Table 1. *Sensory analysis*

Ratio	Comparison	Functional Relevance
Somatosensory (SOT)	Condition 2 Condition 1	Subject´s ability to use input from the somato-sensory system to maintain balance
Visual (VS)	Condition 4 Condition 1	Subject´s ability to use input from the visual system to maintain balance
Vestibular (VEST)	Condition 5 Condition 1	Subject´s ability to use input from the vestibular system to maintain balance
Preference (PREF)	Condition 3+6 Condition 2+5	The degree to which a subject relies on visual information to maintain balance, even when the information is incorrect

Protocol

Subjects underwent in random order in different days, with at least three days in between, the balance tests under various sensory conditions prior to and after maximal exercise bout on the cycle ergometer (Fig. 1).

Pre-exercise protocol was comprised of standard SOT and HS SOT conditions based on the EquiTest system (Smart EquiTest System Operators Manual, Version 7.04), only in case of HS SOT head motions in two planes was added. In the SOT, during the first three conditions with eyes open, eyes closed, and sway-referenced vision the support surface was fixed and during the same next three conditions the support surface was sway-referenced. During the HS SOT subjects performed motions of the head in yaw as well as in roll and pitch planes while their eyes were closed and support surface was either fixed or sway-referenced.

After exercise only two static conditions with subjects eyes open and closed and two dynamic with their eyes closed and sway-referenced vision were repeated. These were selected in accordance with literature (20-22) and in case of dynamic balance also on basis of pre-exercise results of equilibrium score with its the lowest values. Moreover, different visual conditions allow evaluating the stabilising role of vision on balance, known as a Romberg quotient (the ratio of COP in EC and EO conditions).

Subjects stood on the platform barefoot with both feet apart and arms by their sides within the visual surround for three periods of 20 seconds (3 s rest in between) in each condition. They were instructed to minimise postural sway by standing as still as possible. Laboratory assistant stood behind of the subjects to impede a possible fall.

An exercise bout on the cycle ergometer (Ergometrics 800, Ergoline) with an incremental protocol to exhaustion was employed. Following a 3 minutes of warm up at the revolution rate of 40 to 65 W, the initial workload calculated as a 1.5 x bodyweight, was progressively increased by 25 W every 3 minutes. Verbal encouragement was provided in order to achieve maximal intensity of exercise assessed by heart rate, blood lactate, and perceived exertion. Subjects stopped exercise abruptly, without cool down. Twenty to twenty-five seconds after cessation of exercise, measurement of postural stability in selected conditions were repeated, identical to prior exercise.

During exercise on the cycle ergometer as well as during standing on the stabilographic platform the parameters of ventilation (Cortex Biophysik MetaMax 3B) and heart rate (Polar S810, Finland) were continuously monitored.

Blood samples from the fingertip were taken in the 6th minute of recovery for the estimation of lactate concentration (Arkray Lactate Pro, Japan). Enzymatic method was used for the analysis.

The subjective level of exertion was estimated during the exercise by means of the Borg´s 6 to 20 Rating of Perceived Exertion Scale (23), which was documented to correlate closely with several physical

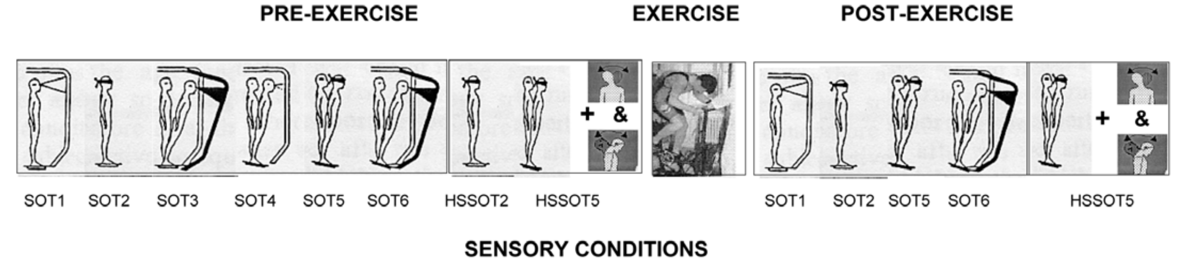

Fig. 1. *Schematic representation of an experimental protocol. Following SOT and HS SOT conditions were used prior to and after maximal exercise: (SOT 1) Fixed support surface and visual surround, eyes open; (SOT 2) Fixed support surface, eyes closed; (SOT 3) Fixed support surface, sway-referenced vision; (SOT 4) Sway-referenced support surface, fixed visual surround, eyes open; (SOT 5) Sway-referenced support surface, eyes closed; (SOT 6) Sway-referenced support and vision; (HS SOT 2) Fixed support surface, eyes closed, roll and pitch head motions; (HS SOT 5) Sway-referenced support surface, eyes closed, roll and pitch head motions.*

variables, including heart rate and lactate production (24). Standardized rating instructions were given before exercise, as described by Borg (25). The rating scales were taped in front of the subjects while they performed the exercise. In the last 15 s of each 3-minute period of cycling they were requested to provide a rating of how hard the exercise feel.

Statistical analyses

A paired t-test was employed to determine the statistical significance of differences between sway variables prior to and after exercise in athletes and non-athletes; $p < 0.05$ was considered significant.

Results

Physiological response to maximal exercise in athletes and non-athletes

All subjects perceived the exercise either as very hard or extremely hard, corresponding to a rate of 18 or 19 on the Borg´s scale (23). Because a rating of 20 is rarely given by subject, such RPEs are considered as a strenuous exercise (25).

Blood lactate, as an indirect indicator of anaerobic glycolysis activation, was after maximal exercise similar in athletes 10.1 ± 1.9 mmol·l^{-1} and non-athletes 9.8 ± 1.2 mmol·l^{-1}, respectively.

Maximal values of ventilation in these groups of subjects were 161.58 ± 11.2 l·min^{-1} and 158.48 ± 12.9 l·min^{-1}, respectively. Non-athletes achieved after exercise higher maximal values of heart rate 189.0 ± 8.3 beats·min^{-1} than athletes 182.8 ± 6.0 beats·min^{-1}.

Postural sway response to maximal exercise in athletes and non-athletes

The equilibrium score (Fig. 2) in athletes did not differ significantly in static conditions after exercise as compared to baseline neither with eyes open (95.75 ± 0.80 and 90.44 ± 3.97 %, respectively) nor with eyes closed (93.06 ± 1.79 and 87.00 ± 4.19 %, respectively). On the other hand, this parameter in conditions of sway-referenced support was significantly (p < 0.01) lower than prior to exercise as with eyes closed (78.11 ± 4.10 and 54.56 ± 14.63 %, respectively) as with sway-referenced vision (81.54 ± 4.57 and 56.50 ± 13.91 %, respectively). Within the third trial (the final 20-seconds of the first minute of recovery) its values nearly returned back to the baseline in static, but not in dynamic conditions.

Similarly, this score in non-athletes decreased after exercise from 93.63 ± 0.80 to 90.00 ± 3.43 % in condition 2 as well as from 78.35 ± 5.27 to 58.29 ± 12.28 % in condition 5, however its post-exercise values were slightly higher than in athletes. It is very probably due to shorter duration of exercise (10.97 ± 3.93 and 25.21 ± 7.80 min, respectively) as a consequence of different level of physical performance in both groups examined.

In remaining SOT conditions there were no differences in this parameter prior to exercise between athletes and non-athletes. By adding yaw head movement in HS SOT, the equilibrium score in condition 2 did not differ in athletes and non-athletes (88.72 ± 1.99 and 88.78 ± 2.13 %, respectively), however its values were significantly (p < 0.05) lower in non-athletes as compared to athletes (52.87 ± 7.68 and 61.51 ± 4.52 %, respectively) in condition 5.

In highly skilled athletes also roll and pitch head motions was added to even more disturb vestibular input since any changes prior to and after exercise in the equilibrium score in standard SOT condition 5 were observed. Such a head movements during standing on sway-referenced support surface with eyes closed caused significant (p < 0.01) decrease of equilibrium score from 60.00 ± 7.78 to 30.00 ± 13.10, 47.00 ± 8.30, and 54.60 ± 9.00 %, respectively in three post-exercise trials.

Furthermore, pre-exercise equilibrium composite score was similar in athletes and non-athletes (86.21

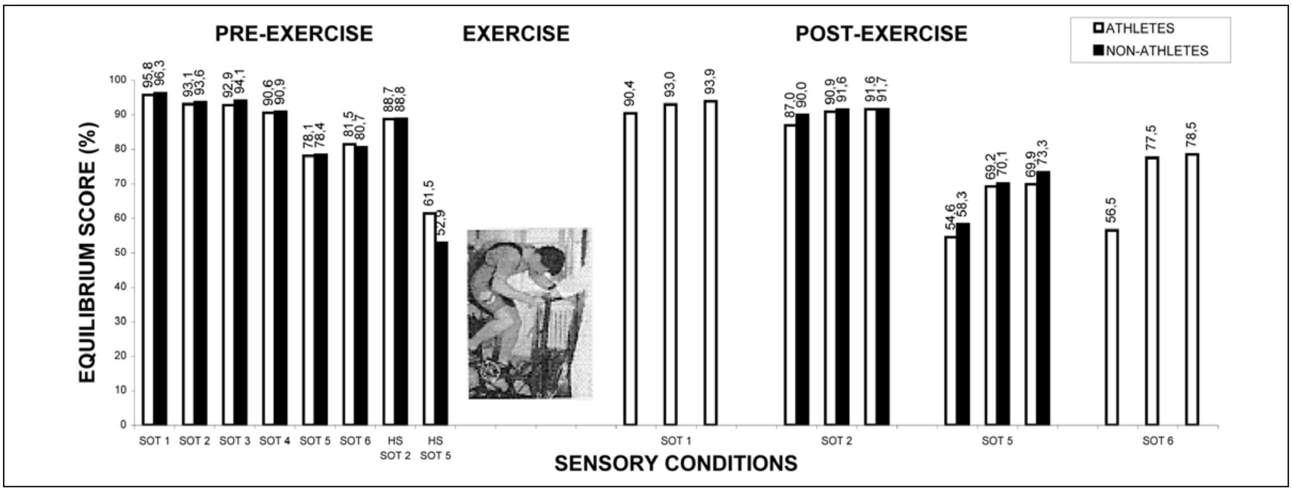

Fig. 2. *Equilibrium score in different SOT and HS SOT conditions prior to (an average of three 20 seconds trials) and after maximal exercise (a three 20 seconds trials) in athletes and non-athletes*

± 2.78 and 86.60 ± 3.10 %, respectively). However, because of reduction the measurements after exercise in the present study, post-exercise values could not be calculated.

Concerning the strategy score (Fig. 3), no significant changes in athletes in static conditions prior to and after exercise with eyes open (97.23 ± 0.71 and 93.89 ± 2.37 %, respectively) as well as with eyes closed (96.12 ± 1.40 and 90.30 ± 3.77 %, respectively) were found. Contrary to this, in conditions of sway-referenced support its values significantly ($p < 0.01$) decreased as when subject´s eyes were closed (81.37 ± 5.53 and 59.11 ± 17.19 %, respectively) as when vision was sway-referenced (85.17 ± 4.27 and 70.67 ± 7.76 %, respectively). It reflects tendency to use both, ankle and hip strategy to maintain postural stability.

In non-athletes, the strategy score also decreased after exercise from 96.00 ± 1.99 to 93.56 ± 3.13 % in condition 2 and from 81.50 ± 9.34 to 75.71 ± 6.60 % in condition 5, however its post-exercise values were higher than in athletes, similarly as in case of equilibrium score.

Sensory analysis revealed that pre-exercise values of somatosensory, visual, vestibular, and visual preference ratios were similar in both group examined (Fig. 4). After exercise, the vestibular ratio significantly decreased from 81.57 ± 4.07 to 60.33 ± 8.09 %, whereas any changes in somatosensory one were observed (97.19 ± 1.85 and 96.20 ± 3.13 %, respectively), indicating that vestibular is more affected by exercise than somatosensory system.

However, it has been proved only in athletes. As post-exercise measurements of postural stability under condition 1, 3, 4, 6 in non-athletes were reduced, sensory ratios in this group could not be calculated. Also, absence results of equilibrium score in condition 3 and 4 after exercise in both groups did not allow calculating neither visual nor its preference ratio. Further studies are needed to obtain these information.

Discussion

Impairment of postural stability immediately after maximal exercise is very probably due to more marked ventilation as a means of respiratory compensation of lactate induced metabolic acidosis. Despite the fact that increased concentration of hydrogen ions is partly compensated by the buffer system, it also stimulates the respiratory center and increases ventilation. This may be documented by its higher values after such

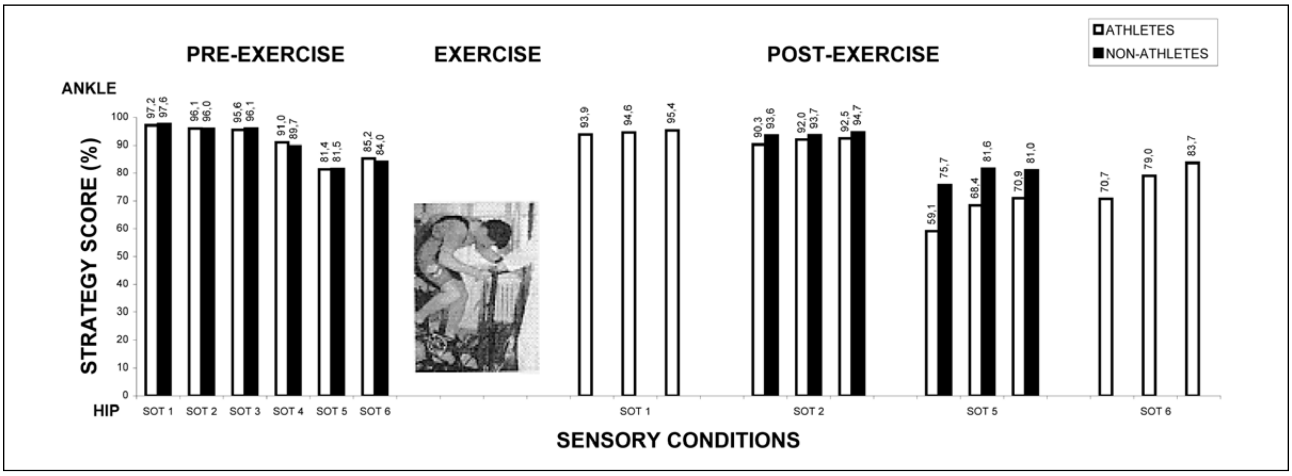

Fig. 3. *Strategy score in different SOT and HS SOT conditions prior to (an average of three 20 seconds trials) and after maximal exercise (a three 20 seconds trials) in athletes and non-athletes*

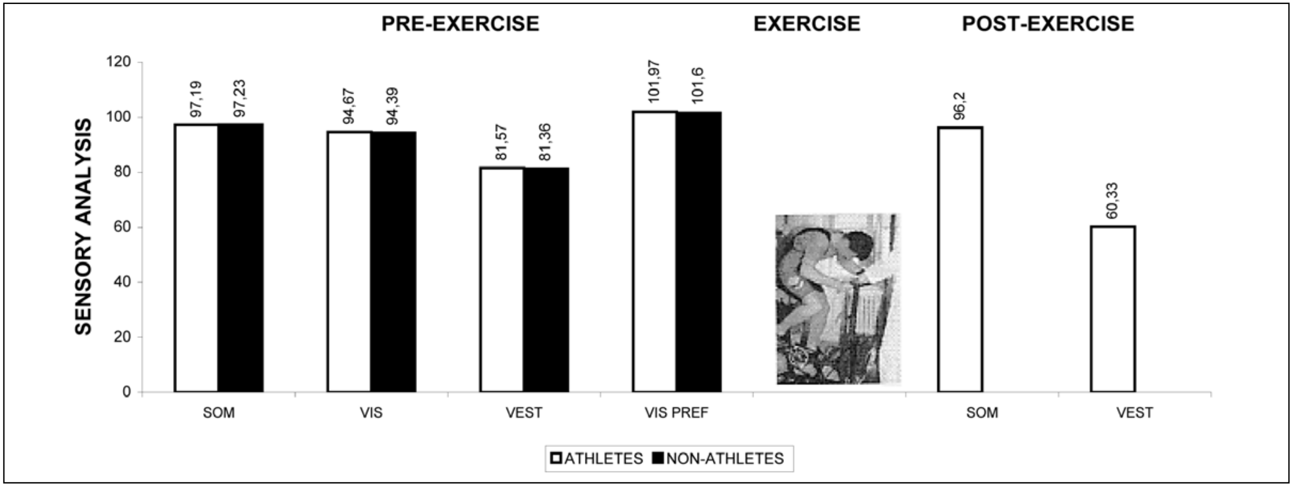

Fig. 4. *Sensory analysis prior to and after maximal exercise in athletes and non-athletes*

an exercise in comparison with baseline. In addition, ventilation remained temporarily elevated and only then started to decrease gradually back to the resting level. Similar trend was evident for heart rate.

Besides blood lactate increase, maximal exercise is also associated with increasing oxygen deficit. Its repayment during recovery also contributed to post-exercise elevation of ventilation and heart rate.

As balance is influenced by body recoil resulting from heart rate action and breathing (26), their exercise induced increase could have affected postural control system. However, in regard to heart rate, experiments with different exercise loads indicate that this factor and body sway does not correlate (3). Accordingly, cardiovascular response to exercise seems not to play essential role in maintenance of balance.

On the other hand, several reports (26-33) have shown that higher breathing rate significantly affect postural stability.

Besides higher respiration, also fatigue might partly impair postural stability. However, such an effect is usually a consequence of prolonged exercise, as shown by Lepers et al. (16) after 25 km running and 1 h 44 min cycling, respectively or Derave et al. (5) after 30 min of treadmill walking and running, respectively.

Therefore it may be assumed that impairment of postural stability after maximal exercise was mediated mainly by hyperventilation. This assumption may be corroborated by close correlation between the movement center of gravity and level of ventilation in recovery phase after such an exercise, similarly as has been shown in case of static balance after short-term abruptly instituted maximal exercise (4).

In sports dependent on post-exercise postural stability, re-adjustment of such an impaired balance is considered as an important ability. It is provided by muscle synergies, ankle and hip strategy (34). Most of the corrective movements take place in the ankle joints, to a lesser degree in the knees and hips (35). This process involves information from the brain based on the visual, somatosensory, and vestibular inputs. Consequently, factors such as hyperventilation or, in part, fatigue may affect several links of the postural control chain.

Results of sensory ratio indicate that inadequate vestibular feedback is the most significant sensory deficit contributing to the post-exercise postural instability. It may be ascribed to the hyperventilation, known to disrupt mainly mechanisms mediating vestibular compensation, and at least partly peripheral and central somatosensory signals from the lower limbs (32).

It is evident in decreased equilibrium score in condition 5 and 6, during which both the support surface and visual references are simultaneously altered. In such a case when as visual as proprioceptive information from lower limbs are reduced, postural control relies mostly on vestibular inputs (36,37) and hence may be preferentially affected by hyperventilation. Besides its exercise induced increase, also post-exercise rotation in the pitch plane might partly increase a respiratory frequency due to shortening of the interval between inspirations (38). Though this factor may contributed to the lowest equilibrium score recorded when subjects performed roll and pitch head motions while surface was moved relative to their body sway, in particular it is a consequence of disrupted function the otolith inputs by such a movement (39).

In addition, postural stability may deteriorate when not only vestibular, but also neck information is not properly coupled (40). It is known in case of neck fatigue producing anomalous proprioceptive input to the central nervous system and a lasting sense of instability (41). In fact, stimulation of the neck proprioceptors and the otolithic organs, both sensitive to linear head accelerations (42) as well as larger vertical head movement and its acceleration pattern are more evident during running than during cycling (16) or walking (5). However, the over-stimulation of the vestibular centre by excessive head oscillations not even after prolonged running does not significantly affect its sensitivity threshold and therefore this phenomenon does not play a key role in the post-exercise impairment of postural stability (43).

Similarly, visual input is less stimulated by the moving field of vision during cycling in comparison with other forms of locomotion, for example running (5,6,16). Because of reduced post-exercise measurements of postural stability in the present study, its contribution on balance impairment cannot be ascertained. Anyway, the grade of visual compensation for body balance may be evaluated by the ratio of sway velocity in eyes closed and eyes open conditions. Surprisingly, there were no significant differences in equilibrium score between eyes open and eyes closed neither prior to nor after exercise. Though it may be in part ascribed to the selection of athletes, very probably it reflects their training background, indicating that they were able to use the remaining sensory modalities to compensate the lack of vision to maintain balance after exercise. This finding is in agreement with the reports of several authors (10,44) who documented that visual contribution to postural stability is improved by training.

It appears that stimulation of vestibular, somatosensory, and visual inputs during cycling is relatively low as compared to other forms of exercise bouts and therefore one would not expect to be particularly affect postural control system, namely those concerning highly skilled athletes. In such a case, exercise induced hyperventilation and fatigue reflecting its intensity and duration take more essential place in balance impairment.

Both factors are probably responsible for decreased preference in ankle strategy after exercise in condition

5 including sway-referenced support and eyes closed. In part, shift to the hip (abductor/adductor) control reflecting medio-lateral balance (45), may be associated with hyperventilation known to increase sway more in sagittal than frontal plane (32). However, these changes in post-exercise postural strategies are very probably due to central (3) and in particular peripheral fatigue of the neuromuscular system (2). According to Lundin et al. (46) plantar flexor and dorsiflexor fatigue increase postural sway amplitude. As platform is moved proportional to the subject´s antero-posterior body sway (17) and in side-by-side stance antero-posterior balance is under ankle (plantar/dorsiflexor) control (45), decreased preference in ankle strategy after exercise is very probably due to by such a fatigue.

This finding is in accordance with several studies that documented higher increase in the medio-lateral than antero-posterior direction after exercise. It has been documented during aiming a rifle after an exercise bout simulating cross-country ski racing (47) or after specific tasks in acrobatic sports, such as gymnastics (10), rockenroll (11) and dance (48).

However, in the present study such a phenomenon has been found only in dynamic conditions. Despite strenuous exercise was applied, during standing on the fixed support surface as with eyes open as eyes closed any significant differences in sway variables were observed. It is accepted that there is certain degree of overlap or redundancy within postural control system in static conditions, and therefore one can suggests the static posturography not to be enough sensitive for the evaluation of exercise effect on balance, namely those concerning highly skilled athletes. In addition, such a slight detrimental effect of exercise on static balance has been found to be only short-lasting, similarly as documented by Nardone et al. (2) and Zemkova, Hamar (7) after cycling, Nardone et al. (2) after running or Nardone et al. (1) after uphill walking, all of them with intensity above anaerobic threshold.

Thus, assessment of postural sway response in dynamic conditions may be assumed as a more sensitive and hence more suitable method for elite athletes. Moreover, dynamic posturography provide additional useful information related to strategy preference and ability to use inputs from vestibular, somatosensory, and visual systems to maintain balance. In addition, cross sectional study of Diard et al. (49) revealed differences between athletes with different demand on balance abilities, indicating that such a method may be applied not only for assessment acute effect of exercise on postural stability but also for training control (50,51) and talent identification too (52,53).

Conclusion

The present study showed no differences between pre- and post-exercise values in equilibrium score, strategy score, and sensory ratios in static conditions. In contrast, these values significantly decreased in dynamic conditions, indicating that these more sensitive reflect changes in postural stability induced by exercise.

It is assumed that hyperventilation as a consequence of respiratory compensation of lactate induced metabolic acidosis caused by maximal exercise is responsible for impaired postural stability. Metabolic response to exercise, hence, plays an important role in maintenance of balance. This fact has to be taken in account in sports dependent on post-exercise postural stability, such as biathlon, gymnastics, rockenroll, figure skating, basketball and so forth.

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Address for correspodence:
Erika Zemková, Ph.D.
Department of Sports Kinanthropology
Faculty of Physical Education and Sport, Comenius University
Svobodovo nábrežie 9,
814 69 Bratislava, Slovakia
E-mail: zemkova@yahoo.com
Tel: 00421-2-54411624

Author's contribution
A – Study Design
B – Data Collection
C – Statistical Analysis
D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
G – Funds Collection