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THE ACUTE AND LONG-TERM EFFECT OF DIFFERENT SENSORIMOTOR EXERCISES ON NEUROMUSCULAR PERFORMANCE

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Abstract

The paper provides an overview of our findings on acute balance adjustments while performing different forms of sensorimotor exercise, as well as its adaptive changes due to systematic training programs in various population. Postural stability was evaluated under both static and dynamic conditions using either wobble board or antero-posterior and medio-lateral randomly moving platform. The COP velocity was registered at 100 Hz by means of posturography system FiTRO Sway check based on dynamometric platform. Results showed improvement of balance after all sensorimotor exercises applied, i.e. serial mechanical proprioceptive stimulation in older women, task-oriented proprioceptive exercise in untrained individuals, combined agility-balance exercises in elite basketball players, and instability resistance exercises in athletes with previous ACL injury. However, both acute adjustments and adaptive changes of balance have been found to depend on exercise mode used. Therefore, further studies are needed to provide scientific guidelines which one is the most effective and appropriate for related population. Nevertheless, sensorimotor exercises represent an efficient means for enhancement of neuromuscular performance enabling maintenance of balance under static and dynamic conditions. It may be of potential use also for prevention and/or rehabilitation of injuries.

Key words: *acute adjustments, adaptive changes, postural sway, sensorimotor exercises*

Introduction

It has been found that postural sway response to exercise depends on its type (1, 2), intensity (3), duration (4), form of muscle contraction (5), and activation of muscle fibers (6).

As a possible physiological mechanisms of post-exercise balance impairment may be considered fatigue (1,4,7-11), hyperventilation (3), deterioration of cutaneous, proprioceptive, vestibular, and visual inputs (12,13), muscle damage, dehydration, hyperthermia, dizziness, and so forth.

However, there is different magnitude of post-exercise balance impairment and speed of its readjustement to pre-exercise level. Overall, we summarized our findings (14) as follows:

a) Short-term intensive exercises → more marked ventilation → high increase in postural sway but fast readjustment;
b) Prolonged exercises of moderate intensity → more profound fatigue → slight but longer balance deterioration;
c) Bouncing exercises → intensive proprioceptive stimulation → great and long duration of balance impairment.

Such altered postural stability after exercise may affect sport performance and/or increase risk of injuries. Indeed, a correlations have been reported between static postural variables and competition level in shooters (15) and basketball players (16). In this cohort, Era et al (17) have shown that less than 10% changes in postural sway determine the outcome of rifle shooting at elite level. Moreover, Hoffman et al (18) found that exercise intensity has minimal effect on accuracy of prone shooting, but affects these measures during shooting in standing position. It may be assumed that more marked ventilation rather than fatigue is responsible for greater postural sway.

On the other hand, a soccer match induced fatigue has been found (19) to affect dynamic balance both with eyes open and eyes closed, which may be ascribed to mainly the deterioration of proprioceptive feedback control of postural stability.

Also an intensity of proprioceptive stimulation during bouncing exercises has been found to significantly influence feedback mechanisms involved in balance control. This effect depends not only on type of exercise (12) but also on height of the jumps (aerobic vs. maximal jumps) (20) and their duration (21).

The present study provides an overview of our findings on acute balance adjustments while performing different forms of sensorimotor exercise, as well as its adaptive changes due to systematic training programs in various population. Postural stability was evaluated under both static and dynamic conditions using either wobble board or antero-posterior and medio-lateral randomly moving platform. The COP velocity was registered at 100 Hz by means of posturography system FiTRO Sway check based on dynamometric platform (www.fitronic.sk). Information on other diagnostic and training systems can be find in related articles.

Acute balance adjustments

It is known that short-term warm-up in form of walking or cycling at low intensity (9), balancing on foam or wobble board (22), vibration of appropriate frequency, amplitude, and duration (23) temporary improves balance.

On the other hand, stretching of calf muscles has been reported (22) to impair balance. Even slightly higher postural sway may be observed when is performed under influence of proprioceptive stimulation applied to lower limbs (24).

Currently mainly various balance exercises performing concurrently with secondary tasks are used in sport and rehabilitation practice. However, contrary to strength research, scarce reports demonstrate acute balance adjustments during sensorimotor exercises. Therefore, some examples of our investigations in this area of research are provided.

a) The effect of serial mechanical proprioceptive stimulation on postural sway

The effect of serial mechanical proprioceptive stimulation of the same frequency and amplitude, however of different duration (15, 60, 180, and 360 seconds) on parameters of static and dynamic balance (antero-posterior and medio-lateral randomly moving platform) was evaluated (25). Proprioceptive stimuli were applied by means of special strength exercise device producing short-term counter movements (at the frequency of 10 Hz and amplitude of 3 mm eliciting force peaks of 3 g within 3 ms corresponding to the force gradient of 300 N/ms) developed at our department by Hamar (26). It has been found that prolonged proprioceptive stimulation applied to lower limbs transiently impairs static balance, but facilitates dynamic balance adjustment leading to its temporary improvement. In both cases such effects become more pronounced as duration of stimulation increases.

In other study (27) parameters of balance were compared after lower limbs resistance exercise (6 sets of 6 semi-squats with an additional load of 75% of body weight, each session separated by 2 min of rest) performed under influence of proprioceptive stimulation and those under normal conditions. Vertical counter shocks (frequency10 Hz, amplitude 3 mm) were applied by means of a special device as described above (26). Results showed that lower limbs resistance exercise in form of semi-squats performed under influence of proprioceptive stimulation has in early phase of recovery more detrimental effect on parameters of balance than those performed under normal conditions. It means that additional proprioceptive stimulation enhances an acute effect of lower limbs resistance exercise on parameters of balance.

b) The effect of task-oriented proprioceptive exercise on sensorimotor parameters

We also evaluated (28) the effect of task-oriented proprioceptive exercise (20 sets of 60 stimuli with 2 min rest in-between) on sensorimotor parameters. The task of the subject was to hit the target by shifting COM in one of the four directions according to position of stimulus on the screen. Sensorimotor parameters including distance, time and velocity of sway trajectory were registered during standing on unstable spring-supported platform equipped with PC system for feedback monitoring of COM movement that was developed at our department by Hamar (29).

Results showed that response time and distance of sway movement decreased, and sway velocity increased with repeated trials of sensorimotor exercise. More specifically, subjects responded to visual stimuli faster and more precise by horizontal shifting of COM in one of the four directions according to position of stimulus on the screen. Such a more precise of COM perception and faster reaction to visual stimuli may be ascribed to enhancement of visual feedback control of body position.

These findings indicate that task-oriented proprioceptive exercise acutely improves sensorimotor performance during practice and may be potentially used for rehabilitation purposes.

c) The effect of reaction tasks on postural sway

It has been investigated (30) the reaction time and sway velocity while responding on visual stimuli concurrently with balancing on wobble board. A group of PE students responded in random order on either one or two visual stimuli while standing on unstable support surface for a period of 3 min. During the task execution both sway velocity and reaction time were measured. The COP velocity was registered at 100 Hz by means of posturography system FiTRO Sway check based on dynamometric platform. Simple and multi-choice reaction time was measured using FiTRO Reaction check.

Results showed no changes in simple reaction time while balancing on wobble board. However, multi-choice reaction time significantly increased from an initial 5-sec to the final 5-sec period of the test. On the other hand, the COP velocity gradually decreased during simple reaction task. When responding on two stimuli, there was a significant decrease in the COP velocity for an initial 2:15 min, which was followed by its slight increase toward the end of the test. Interestingly, multi-choice task induced greater balance improvement as compared to simple reactions.

It was concluded that reaction time increases while balancing on wobble board, whereas sway velocity declines when concurrently performing reaction task.

d) The effect of resistance exercise performed on wobble board on postural sway

Variety of exercises and methods are incorporated into balance training. However, there are no scientific guidelines concerning effective practice schedule for improvement of balance. Therefore, using retention tests we investigated (31) a) optimal practice-rest ratios, and b) efficient exercise mode for balance training. A group of 14 PE students underwent different combinations of practice and rest on two balance tasks, making the percentage of time actually spent in practice (20%, 40%, 60% and 80%, respectively) of the total 30-min period. Thus, the protocol was as follows: a) 6 min practicing (12 x 30 sec) / 24 min rest (12 x 2 min), b) 12 min practicing (12 x 1 min) / 18 min rest (12 x 1.5 min), c) 18 min practicing (12 x 1.5 min) / 12 min rest (12 x 1 min), d) 24 min practicing (12 x 2 min) / 6 min rest (12 x 30 sec). This schedule was examined under different conditions: a) balancing or performing squats on wobble board, b) performing squats with different velocities while standing on wobble board, c) performing squats with different additional loads (AL) on wobble board. The learning was tested by administering a transfer test, which was given on the second day. The COP velocity was registered at 100 Hz by means of posturography system FiTRO Sway check based on dynamometric platform. While exercising and standing on stabilographic platform, cardiorespiratory parameters were monitored using breath-by-breath system Spiroergometry CS 200. Velocity of movement during squats was measured using the FiTRO Dyne Premium.

Results showed that for balancing on wobble board, the optimal condition for learning occurred when 80% of the time was spent practicing. However, by adding squats, such a combination of 2 min practice and 30 sec rest induced a gradual increase in ventilation and heart rate (peak values about 13.4%). Subjects also reported fatigue in lower limbs, which influenced their ability to perform exercise properly. The transfer test showed that for squats performing on wobble board, the optimal condition for learning occurred when 40% of the time was spent practicing. In addition, retention tests of various exercise mode showed that for improvement of balance are more efficient a) squats performing on wobble board than balancing on unstable surface, b) explosive squats (~180 cm/s) than those performing with slower velocity (~90 cm/s), c) squats on wobble board with lower AL (e.g., 25% of body weight) than those performing with higher AL (50% and 75% of body weight).

These findings indicate that explosive squats performing on wobble board with AL of 25% body weight for 1 min with 1.5 min rest in-between (i.e., 12 min practicing / 18 min rest in 30 min session) is effective schedule for improvement of balance. Previous experience also showed that adaptive changes in balance performance of elite athletes may be induced if such a schedule is provided 4-5 days per week for >25 training days.

Chronic balance adaptations

Besides traditional coordination, balance and resistance exercises, various aerobic activities or tai-chi, recently mainly whole body vibrations became a part of athletic training and rehabilitation in order to improve postural stability (32-36).

Also a combined balance and strength training using special exercise devices are widely employed in sport and rehabilitation setting. For instance, it has been found (37-42) that 4-week of resistance exercise in form of squats performed on an unstable surface in an altered-G environment improves both strength and postural stability. Such exercises may be applied in training of highly skilled athletes, in pre- and in-flight regimens for astronauts, and in rehabilitation of bed-ridden patients.

However, out of the playing field or gym mainly instability resistance exercises (43) are being preffered. Though a vide variety of studies have been carried out with aim to evaluate their effect on neuromuscular performance in various population, a little is known about adaptive changes after a novel form of sensorimotor exercises performed concurrently with secondary tasks (44,45).

Therefore, our investigations concerning various forms of sensorimotor training in the elderly, elite athletes, untrained individuals, and those following lower limb injury are being provided.

a) The effect of 3-month serial mechanical proprioceptive stimulation on neuromuscular perfomance in older women

This study examined changes in neuromuscular performance in older women after 3-month of proprioceptive stimulation training applied to lower extremities. They undervent (3-times a week) two different forms of exercise, either stood with slightly flexed knees or performed semi-squats on vibrating platform. The intensity of exercise in the first case increased by lengthening the time of stimulation, whereas in the second by additional load. Proprioceptive stimuli were applied by means of special strength exercise device producing short-term counter movements at the frequency of 10 Hz and amplitude 3 mm as described above (26).

It has been found that experimental group improved significantly in agility (46), balance (47), and explosive power of lower limbs (48). This effect was more evident when during vibrations the resistance exercises, e.i., semi-squats were performed. Contrary to this, control group failed to show any significant improvement in these abilities. Such positive changes may be ascribed to the enhancement of neuroregulatory functions, namely increased rate of motoneuron firing and better synchronisation of motor units activation.

This indicates that in elderly population the mechanical proprioceptive stimulation applied to lower limbs may enhance neuromuscular performance similarly to resistance training. It may have a practical impact on decrease a risk of falling with subsequent reduction of complications affecting namely elderly population.

b) The effect of 3-weeks of task-oriented proprioceptive training on parameters of neuromuscular function in untrained individuals

This study (49) evaluated effects on neuromuscular function following proprioceptive training on unstable spring-supported platform equipped with PC system for feedback monitoring of COM movement developed at our department by Hamar (29). The task of the subject was to hit, as fast as possible, the target appearing randomly in one of the corners of the screen by horizontal shifting of COM. They underwent a 3-week program consisting of 3 sets of 200 stimuli with 5 min rest in-between, 3 times a week. Sensorimotor parameters were evaluated prior to and after the training. These include distance, time and velocity of sway trajectory measured by "Proprio test" consisting of 2 sets of 60 stimuli. In the test subjects had to hit the target by shifting COM in one of the four directions according to position of stimulus on the screen.

Results of the „Proprio test" showed that response time significantly decreased. Though at the same time distance of sway movement also significantly decreased, velocity increased. Substantial share of the improvements took place during initial 6-8 sessions (about 1 week). Also the ability to maintain postural stability on unstable platform significantly improved. On the other hand, there were no changes in the COP velocity registered in static conditions. Training program used has also proved to be insufficient to enhance jumping performance expressed as power in the concentric phase of take off, and height of the squat and countermovement jump. After the same training control group failed to show any significant improvement in parameters of the „Proprio test", dynamic and static balance, as well as explosive power of lower limbs.

It was concluded that task-oriented proprioceptive exercise applied represents a suitable means for enhancement of neuromuscular function enabling more rapid postural sway adjustments in altered surface conditions. It may be of potential use, namely in elderly population, for decreasing risk of falling and reduction of health-related consequences.

c) The effect of 6-week combined agility-balance training on neuromuscular performance in elite basketball players

In this study (50) elite basketball players randomly divided into experimental (EG) and control group (CG) underwent a combined agility-balance training (in duration of 30 min) for a period of 6 weeks (4-5 sessions/week). Both groups performed reaction tasks similar to game-like situations, however EG on wobble boards and CG on stable surface.

Prior to and after the training parameters of agility, balance, speed of step initiation, strength differentiation accuracy, and explosive power of lower limbs were evaluated. Postural stability was assessed under both static and dynamic conditions (wobble board) with eyes open and eyes closed, respectively. The COP velocity was registered at 100 Hz by means of posturography system FiTRO Sway check based on dynamometric platform. Using FiTRO Reaction check simple and multi-choice reaction time was measured. The same system was applied to evaluate the agility performance including reaction and movement task. Speed of step initiation was measured using FiTRO Dyne Premium. Jumping abilities were evaluated by means of FiTRO Jumper (10-sec maximal jumps, CMJ, SJ, DJ45). Using the same system, the subject´s ability to match 50% of their maximal height of the jump was evaluated.

Results showed that a combined agility-balance training improved dynamic balance not only under visual control but also in eyes closed conditions. Training also increased run-out speed that likely contributed to better agility performance, reduced ground contact time during drop jump, and improved the ability to differentiate the force of muscle contraction during repeated jumps. However, such training has been found to be insufficient to improve both simple and multi-choice reaction time, and jumping performance. On the other hand, control group failed to show any significant improvement in examined abilities expect from enhancement of jumping performance (Pact, Δ CMJ & SJ).

It was concluded that balance exercises performed simultaneously with reaction tasks represent an effective means for improvement of neuromuscular performance in elite athletes. However, additional exercises have to be implemented into training program in order to improve reaction time and explosive power of lower limbs.

d) The effect of 12-weeks instability resistance training on neuromuscular performance in athletes with previous ACL injury

In this study (51,52) a group of soccer players after ACL reconstruction underwent two months after rehabilitation a combined balance and resistance exercises (e.g., semi-squats, deep squats, wide-stance squats, one-legged squats, barbell squats performed on various unstable support surfaces) in duration of 30 min for a period of 12-weeks (4-5 sessions/week).

Pre-training measurements showed the non-injured-to-injured leg percent differences of 15.7% for static and 24.5% for dynamic balance. Following the training there were no changes in static balance on both legs, on non-injured and injured leg. Likewise, the dynamic balance did not change while standing on both legs and on non-injured leg, however a significant improvement on injured leg has been found. In addition, sway velocity significantly decreased during bipedal stance on M-L tilted platform but not on those A-P tilted. Furthermore, run-out speed significantly increased on injured leg but not on non-injured leg. On the other hand, any changes in kick-off speed on injured and non-injured leg have been found. Unfortunately, no information on changes in jumping performance has been provided because during pre-training testing most of the subjects were not able to perform SJ and CMJ.

It was concluded that evaluation the efficiency of instability resistance training in dynamic conditions more sensitively reflect adaptation changes in postural control system than stance on stable platform. Also measurement of movement speed seems to be suitable method, whereas using explosive power tests in an early phase of post-rehabilitation is limited.

Conclusions

Investigations on acute balance adjustments showed following results:

a) Prolonged proprioceptive stimulation applied to lower limbs transiently impairs static balance, but facilitates dynamic balance adjustment leading to its temporary improvement. In both cases such effects become more pronounced as duration of stimulation increases. Further, additional proprioceptive stimulation enhances an acute effect of lower limbs resistance exercise on parameters of balance

b) Task-oriented proprioceptive exercise enhances visual feedback control of body position during practice. In particular, subjects are able to respond to visual stimuli faster and more precise by horizontal shifting of COM in one of the four directions according to position of the stimulus on the screen during standing on unstable spring-supported platform equipped with PC system for feedback monitoring of COM movement.

c) Reaction time increases while balancing on wobble board, whereas sway velocity declines when concurrently performing reaction task.

d) Using retention tests showed that explosive squats performing on wobble board with AL of 25% body weight for 1 min with 1.5 min rest in-between (i.e., 12 min practicing / 18 min rest in 30 min session) is effective schedule for improvement of balance. Previous experience also showed that adaptive changes in balance performance of elite athletes may be induced if such a schedule is provided 4-5 days per week for > 25 training days.

Findings on chronic balance adaptations were as follows:

a) Mechanical proprioceptive stimulation applied to lower limbs enhances neuromuscular performance (agility, balance, explosive power) in older women.

b) Task-oriented proprioceptive exercise performed on unstable spring-supported platform equipped with PC system for feedback monitoring of COM movement represents a suitable means for enhancement of neuromuscular function enabling more rapid postural sway adjustments in altered surface conditions. However, such proprioceptive training is insufficient to enhance jumping performance expressed as power in the concentric phase of take off, and height of the squat and countermovement jump.

c) A combined agility-balance training improves dynamic balance not only under visual control but also in eyes closed conditions, increases speed of step initiation, enhances agility performance, reduces drop jump ground contact time, and improves the ability to differentiate the force of muscle contraction during repeated jumps. On the other hand, such training is insufficient to improve both simple and multi-choice reaction time, and explosive power of lower limbs. Therefore, additional exercises focused on development of these capabilities should be implemented into training program.

d) Instability resistance training improves dynamic balance on injured leg and during bipedal stance on M-L tilted platform, as well as speed of step initiation. However, such training is insufficient to enhance kicking performance and static balance.

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