Jumping impairs visual feedback control of body position

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ABSTRACT
Purpose. The aim of this study was to evaluate the effects of maximal rebound jumping on sensorimotor tasks that required visual feedback control in positioning the body.

Methods. A group of 14 university students (age 23.7 ± 2.6 y, height 178.6 ± 9.2 cm, and weight 70.6 ± 11.4 kg) had to hit a target that randomly appeared on one side of a screen by horizontally shifting their centre of mass (COM) in the appropriate direction prior to (as a baseline) and after six 60-second maximal jump exercises. Each response test consisted of 60 targets. The time, distance, and the velocity of the centre of pressure (COP) trajectory between the stimulus’s appearance and its hit, by visually-guiding the COM movement on the screen, were registered by means of a FiTrO Sway Check system using a dynamometric platform. During the sets of jumps, the power of the concentric phase of take off was registered using a FiTrO Jumper recorder.

Results. Results found that after each set of jumping (of around 110 jumps per set), mean response time significantly (p < 0.05) increased from an initial value of 1616 ± 506 ms to 1825 ± 562 ms till the 4th set, with no further increase towards the 6th set. Similarly, the mean distance of COP covered during the response time increased significantly (p < 0.05) from a pre-exercise value of 0.449 ± 0.298 m to 0.550 ± 0.295 m after the 4th set which then plateaued towards the 6th set. However, no significant changes in mean COP velocity were detected.

Conclusion. Rebound jumping negatively affected the visual feedback control in positioning the body. However, after the proprioceptive functions deteriorated to a certain level, there was no further impairment on sensorimotor parameters.

Key words: acute effect, center of mass, jumping, task-oriented sensorimotor exercise, visual feedback

Introduction

Many studies have been carried out to study the effects of different types of exercise on postural stability. For instance, running has been reported to impair postural stability more profoundly than walking [1] or cycling [2]. However, little attention was paid to the intensity and duration of such exercise. Therefore, this study decided to focus on the postural sway response to different forms of exercise and the physiological mechanisms of post-exercise balance impairment (for a review, see [3]).

One of the studies conducted by the authors of this paper [4] proved that despite the same heart rate response, more rapid, intensive, and shorter forms of exercise impair postural stability in the early phase of recovery more profoundly than longer stepwise exercise with a lower contribution to anaerobic glycolysis. Furthermore, prolonged exercise of moderate intensity has been found [5] to cause longer balance disorders as compared to exercise of the same intensity but of a shorter duration. Longer readjustment of postural sway to pre-exercise levels was also observed [6] after upslope treadmill running than after level running which involved different forms of muscle contraction.

On the other hand, a comparison of balance parameters after exercises with different activated muscle fibres showed [7] more profound balance impairment after cycling at higher rather than lower revolution rates only in the initial phase of recovery. In the case of resistance exercise, besides the type of exercise and its intensity (of additional load), the rate of movement, the number of repetitions and sets, the muscle mass activated, and the intensity of proprioceptive stimulation all play a role [8].

Fatigue has been generally proposed [9–12] as the principal factor of post-exercise balance impairment. However, such an effect is usually a consequence of prolonged exercise, as shown by Lepers et al. [2], such as after 25 km running or 1 h 44 min cycling, or by Derave et al. [13] where tests were conducted after 30 min of treadmill walking and running. Similarly, it was suggested by the authors of this paper [5] that more pronounced neuromuscular fatigue resulting from prolonged exercise of moderate intensity is responsible for longer balance disorders as compared to exercise of the same intensity but of a shorter duration.

On the other hand, the contribution of hyperventilation or the deterioration of the proprioceptive, vestibular, and visual inputs on such balance impairment has not been well specified. In fact, it has been shown [4] that more pronounced respiration levels, as a result of compensating anaerobic acidosis caused by abrupt intensive exercise, are responsible for the more pro-
found impairment of postural stability when compared to longer stepwise exercise. This assumption was corroborated by close correlations found between the movement of the centre of pressure and level of ventilation in the recovery phase after such an exercise. This finding is in agreement with several authors' reports [14–17] who documented that a higher breathing rate significantly affects postural stability.

Likewise, in another study conducted by the authors of this paper [8] showed that balance impairment in the early phase of recovery after resistance exercise is a consequence of more marked ventilation rather than fatigue. This effect was more evident with exercises performed with the lower (squats and calf rises) than the upper extremities (biceps curls and presses behind neck).

However, the same ventilation levels may be induced by exercises of different muscle contraction intensity eliciting different levels of proprioceptive stimulation. Indeed, a comparison of sway variables after two forms of resistance exercise which lead to the same ventilation levels showed [18] more profound balance impairment after jumping than after calf rises due to a higher intensity of proprioceptive stimulation. This factor was also suggested to be responsible for greater postural sway after running than after cycling [19]. In other words, the intensity of proprioceptive stimulation during exercise also has an important influence on feedback mechanisms that are involved in the control of balance.

On the other hand, there are only few studies available which evaluated the effects of exercise on the visual feedback control of body position. One of the studies, conducted by the authors of this paper [20], showed that the accuracy of visual feedback control in positioning the body, after maximal rebound jumps, is more compromised in the antero-posterior than in medio-lateral direction. However, this was proved through the use of a visually-guided COM tracking task which did not provide information on the visual feedback control of body position after jumping on the basis of different task-oriented sensorimotor exercises. Therefore the aim of this study was to evaluate the effects of maximal rebound jumps on sensorimotor parameters through a visually-guided COM target-matching task.

**Material and methods**

**Subjects**

A group of 14 university students studying physical education (age 23.7 ± 2.6 y, height 178.6 ± 9.2 cm, and weight 70.6 ± 11.4 kg) volunteered to participate in the study. All of them were informed of the procedures and the main purpose of the study. The procedures presented were in accordance with the ethical standards on human experimentation.

**Study setting**

The subjects’ task was to hit a target that randomly appeared on one side of a screen by horizontal shifting their COM in the appropriate direction of where the stimulus was positioned on the screen prior to (as a baseline) and after six 60-second maximal jump exercises (Fig. 1 a, b). Each response test consisted of 60 stimuli. The time, distance, and COP trajectory velocity between the appearance of the stimulus and its hit by a subject’s visually-guided COM movement, as seen on the screen, were registered by means of a FITRO Sway Check (Fitronic, Slovakia) system using a dynamometric platform.

Figure 1. FITRO Sway Check diagnostic system (a) and the graphic display of an executed task (b)
During the jump sets, the power of the concentric phase of take off was registered using a FiTrO Jumper (Fitronic, Slovakia) recorder consisting of a contact mat, a serial port interface and a special computer program. The program's calculations are based on the contact time ($T_c$) and flight time ($T_f$), as measured by the contact mats, with an accuracy of 1 ms using the formula as follows: $P_{con} = \left(\frac{g^2 \times T_f}{4 \times T_c}\right)$.

**Statistical analysis**

Ordinary statistical methodology including average and standard deviations was used. A paired t-test was employed to determine the statistical significance between the differences between pre- and post-exercise values of the examined abilities; $p < 0.05$ was considered significant.

**Results**

The results found that after jumping (of around 110 jumps per set), the mean response time significantly ($p \leq 0.05$) increased from an initial value of 1616 ± 506 ms to 1825 ± 562 ms till the 4th set, with no further increase towards the 6th set (Fig. 2). Similarly, the mean distance of COP covered during the response time increased significantly ($p \leq 0.05$) from pre-exercise values of 0.449 ± 0.298 m to 0.550 ± 0.295 m after the 4th set and then plateaued toward the 6th set (Fig. 3). However, no significant changes in mean COP velocity were detected (Fig. 4).

**Discussion**

Theoretically, the impairment of sensorimotor parameters after the maximal rebound jumps may be attributed to a deterioration of both motor and the sensory functions. The effect of impairment on the motor side may be assumed from a decrease in power during the concentric phase of take off (initially from the first to last series of jumps by 10.3% and then by 5.3% in the last 5 seconds of jumping). However, such an assumption is questionable due to the results of other studies finding no correlations between postural sway amplitude and ankle joint pronator muscle strength, [21] and maximum inversion and eversion moments [22]. On the other hand, a fatigue-induced delay in the rate of force development has been associated with an increase in unilateral postural sway amplitude [10]. So, one has to admit that this mechanism played a role in the deterioration of completing a visually-guided sensorimotor task.

It is also possible that the sensory system was affected, namely at the peripheral level, through a change in the spindle excitation threshold of the fatigued muscles. Muscle fatigue induces a depression in the spindle afferent fibre discharge, possibly due to a decrease in $\gamma$-motoneurone activation. The gamma system is known to facilitate the alpha motoneurons that control slow-twitch fibres. Assuming a correlation between the activity of the soleus muscle and the COP displacement [12], these fibres are involved in the control of body position. Presumably, it may mainly be a response from the small-diameter III and IV afferents modulating postural reflexes which decreased with repeated contractions [23]. However, besides the impairment of muscle spindle function, the decreased sensitivity of joint receptors and cutaneous mechanoreceptors on the sole, due to their intensive stimulation during jumping, may also be taken in account. The resulting partial reduction of afferent impulses that are utilized in the proprioceptive feedback of body control might also contribute to a less precise perception of COM position and in the regulation of its movement. However, this effect was observed only from the 1st to 4th set.
of 60-second jumping, after which no further increase in the response time nor in the distance of COP movement occurred. This finding may be explained by a lower susceptibility of the already impaired proprioceptors to further mechanical stimulation during the final 2 sets of jumping. A further reduction of proprioceptive acuity in fatigued legs might be also compensated for by alternative sensory inputs from different body segments, namely the trunk and upper-leg muscles. This shift from an ankle to hip body control strategy is the result of more active contractions that are required to perform the sensorimotor task when fatigued. These contractions could originate mainly from the stretch and vestibular reflexes. Since ankle and calf muscle reflex responses could be delayed due to fatigue, other postural reflexes likely became involved in the regulation of COM movement. These compensatory mechanisms could reduce the further negative effects of jumping on the visual feedback control of body positioning.

These findings are in agreement with results found in a previous study done by the authors of this paper [24], where no linear relationship had been found between post-exercise balance impairment and the level of proprioceptive stimulation. Sway velocity increased 36.6% when compared to pre-exercise values after jumps dropped to 75% 1MJ. A further 26.0% increase was observed after jumps dropped to 50% 1MJ. However, despite more than double the number of jumps performed when jumps dropped to 25% 1MJ (196 jumps) as compared to 50% 1MJ (81 jumps), sway velocity only slightly increased (on average 8.4%).

As such, it has to be taken into account that not only the type and intensity of exercise, [18] but also height of the jumps [25] and their duration [24] may play a role in the magnitude of balance impairment. Consequently, this may negatively affect performance and increase the risk of injuries.

Landing on one's feet is an important part in sports performance, such as in dancing, gymnastics and aerobics. From biomechanical analyses, it is known that ground reaction forces in aerobics may reach 3-, 4-, and even 5-times that of body weight [26]. Substantially higher peak forces have been recorded in gymnasts' landings ranging from 8.2 to 11.6 times that of body weight [27]. These athletes often land with minimal flexion at the hip, knees, and ankles, which themselves are used as the primary means of attenuating energy during such landings [28]. In addition, gymnasts are exposed to higher ground reaction forces during drop landings from 60- and 90-cm heights (40.3 N/kg and 56.0 N/kg, respectively) than recreational athletes (27.0 N/kg and 37.4 N/kg, respectively) [29].

It may be assumed that repetitive exposure to such high loads may contribute to the incidence of lower limb injuries. This account for 50% [30] to 64% [31] of all injuries suffered, with the most frequent sites of trauma being the ankle [32], followed by the knee [33].

In particular, the functional instability of the ankle joint is a late complication of 10% to 30% of acute ankle sprains [34]. Functional instability is associated with the decreased strength of ankle musculature, impaired proprioception, loss of balance and ligamentous laxity [35]. Decades ago it was postulated [36] that these injuries could have resulted from delayed reflex responses to stress on ankle ligaments as a result of damage to ankle joint receptors at the time of the initial injury. However, recent evidence [37] suggest that the dynamic control of ankle stability is achieved by feed-forward mechanisms of the central nervous system rather than by means of feedback effected by peripheral reflexes.

Caulfield and Garrett [38] have documented that lateral and anterior force peaks occurred significantly earlier in subjects with functional instability of the ankle joint. Significant differences were seen between groups' time-averaged vertical, frontal and sagittal components of ground reaction force. These ranged from 5% (frontal force) to 100% (vertical force) of body mass. According to these authors, the disordered force patterns observed in subjects with functional instability are likely to results in repeated injury due to a significant increase in stress on ankle joint structures during jump landings. They suggest that these injuries are more likely to result from a deficit in the feed-forward control of ankle joint movement. This is also important during the initiation of a vertical jump as the human body's upward propulsion has been found [39] to depend on the control of forward equilibrium. Due to biomechanical constraints, balance is first lost through a backward shift of centre of pressure. Therefore, the COP is moved forward so as to reach a position favourable to produce a vertical jump.

Tests based on visually-guided COM tracking or on target-matching tasks may provide deeper insight into the changes of postural control induced by exercise. A better understanding of the balance maintenance mechanisms during fatigue [40] may serve as a basis for creating exercise programs focused on the prevention of injuries. Experience has found that task-oriented sensorimotor exercises based on visual feedback control of body position could provide better coordination in stabilizing the body's centre of pressure. Therefore, retraining balance function after lower limb injury using visual feedback exercises could become a promising tool that may complement existing rehabilitation methods.

**Conclusion**

Rebound jumping negatively affected visual feedback control of body position. However, after the proprioceptive functions deteriorated to a certain level, there was no further impairment of sensorimotor
parameters. More specifically, mean response time and the mean distance of COP covered during the response time increased significantly after four sets of jumps (of around 110 jumps per set) out of six sets, with no further changes in the last two. These findings indicate that there is no linear relationship between post-exercise impairment of postural control and the level of proprioceptive stimulation.

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