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Original empirical article

POSTURAL SWAY RESPONSE TO MAXIMAL EXERCISES WITH DIFFERENT FORMS OF MUSCLE CONTRACTION

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Abstract. *The study compares parameters of balance after treadmill upslope and level running involving different forms of muscle contraction. A group of 14 PE students (age 19.2 ± 2.9 years, height 180.0 ± 7.3 cm, weight 69.2 ± 8.4 kg) underwent in different days two stepwise exercise bouts on the treadmill. In both cases, an initial intensity of 5.6 km/h was increased by 1.2 km/h every 1.5 minute up to a maximum point. However, during uphill running the slope of the treadmill was 15%. The duration of level running was longer compared to the upslope running, on average 10 and 14 min, respectively. Thirty seconds before and two minutes after exercises the COP velocity was registered at 100 Hz by means of a posturography system, the FiTRO Sway check based on dynamometric platform. While the subjects were exercising and standing on the stabilographic platform, their cardiorespiratory parameters were monitored by means of the breath-by-breath system, the Spiroergometry CS 200. As intended, there was no difference in the peak of ventilation after upslope and level running (149.3 ± 13.1 l/min and 146.7 ± 12.6 l/min, respectively). Likewise, both exercises elicited similar heart rates (190.0 ± 11.1 bpm and 182.2 ± 8.9 bpm, respectively). In addition, sway velocity in an initial 5-second period of recovery did not differ after both exercises (37.2 ± 3.8 mm/s and 34.7 ± 3.1 mm/s, respectively). However, its longer readjustment to the pre-exercise level was observed after uphill running compared to flat running. These differences after about 50 seconds of recovery were even significant ($p \leq 0.05$). In both cases, the values did not return to the baseline within the examined two minutes after the exercises. It may be concluded that postural sway is only slightly higher after upslope than level running but its readjustment to pre-exercise is substantially slower. Such longer balance impairment may be attributed mainly to differences in the unique properties of predominantly concentric rather than eccentric contractions.*

Key words: *form of muscle contraction, level running, postural stability, upslope running*

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INTRODUCTION

As is known from biomechanical analyses, substantially higher vertical ground reaction forces are produced during running as compared to cycling. It may be assumed that running elicits a more profound stimulation of muscle spindles, joint receptors and cutaneous mechanoreceptors in the sole, leading to the impairment of their sensitivity. It has been suggested (Zemková et al., 2005) that such a deterioration of proprioceptive feedback control of balance contributes to the higher increase in postural sway after running as compared to cycling.

However, in this study it remains unclear how different forms of muscle contractions influence postural stability. While during cycling the triceps surae mostly undergoes a shortening contraction (Hull and Hawkins, 1990), and a rather large percentage of the gait cycle is performed by eccentric contractions of the lower limb muscles, particularly the triceps surae (Inman et al., 1981).

There is quite lot of evidence on both acute and adaptive changes in strength due to concentric and eccentric exercises. These are attributed to differences in the properties of both contractions, including characteristics such as cross-bridge activity, motor unit activity, maximal activation, afferent feedback, reflexes, etc. (Enoka, 1996).

It may be assumed that such differences may also play a role in balance readjustment after uphill and downhill running involving predominantly either concentric or eccentric contractions of the leg muscles. As we were not able to provide a decline on the treadmill, flat running was employed.

To this end, we compared parameters of balance after treadmill upslope and level running involving different forms of muscle contraction.

METHOD

Participants

A group of 14 PE students (age 19.2 ± 2.9 years, height 180.0 ± 7.3 cm, weight 69.2 ± 8.4 kg) volunteered to participate in the study. All of them were informed of the procedures and of the main purpose of the study.

Test protocol

The subjects underwent, on different days, two stepwise exercise bouts on the treadmill. In both cases, an initial intensity of 5.6 km/h was increased by 1.2 km/h every 1.5 minute up to a maximum. However, during uphill running the slope of the treadmill was 15%. The duration of level running was compared to upslope running for a longer period of time, on average 10 and 14 min, respectively.

Thirty seconds before and two minutes after exercise, the COP velocity was registered at 100 Hz by means of a posturography system, the FiTRO Sway check based on a dynamometric platform. Average values of 5-second intervals were used for the evaluation. The subjects were instructed to minimize postural sway by standing as still as possible.

While the subjects were exercising and standing on the stabilographic platform, their cardiorespiratory parameters were monitored by means of a breath-by-breath system, the Spiroergometry CS 200.

Procedure

Ordinary statistical methods including average and standard deviations were used. A Wilcoxon test was employed to determine the statistical significance of differences between pre- and post-exercise values of parameters of balance, while the $p < 0.05$ level was considered significant.

RESULTS

As intended, there was no difference in the peak of ventilation after upslope and level running (149.3 ± 13.1 l/min and 146.7 ± 12.6 l/min, respectively) (Figure 1). Likewise, both exercises elicited similar heart rates (190.0 ± 11.1 bpm and 182.2 ± 8.9 bpm, respectively) (Figure 2).

In addition, sway velocity during an initial 5-second period of recovery did not differ after both exercises (37.2 ± 3.8 mm/s and 34.7 ± 3.1 mm/s, respectively) (Figure 3). However, its longer readjustment to the pre-exercise level was observed after uphill running compared to flat running. These differences after about 50 seconds of recovery were even significant ($p \leq 0.05$). In both cases the values did not return to baseline within the examined two minutes after exercise.

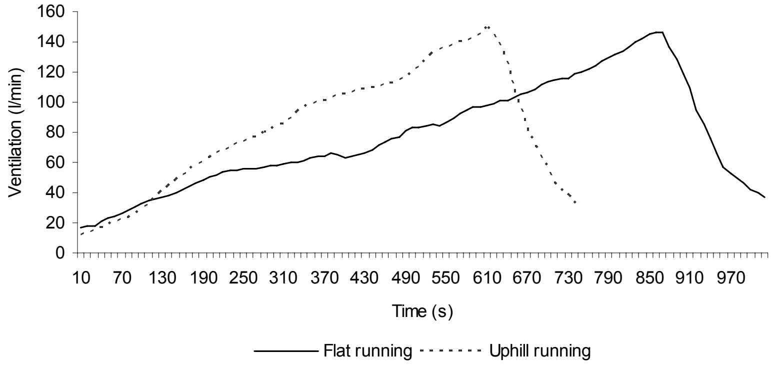

Fig. 1. Ventilation prior to, during and after flat and uphill running

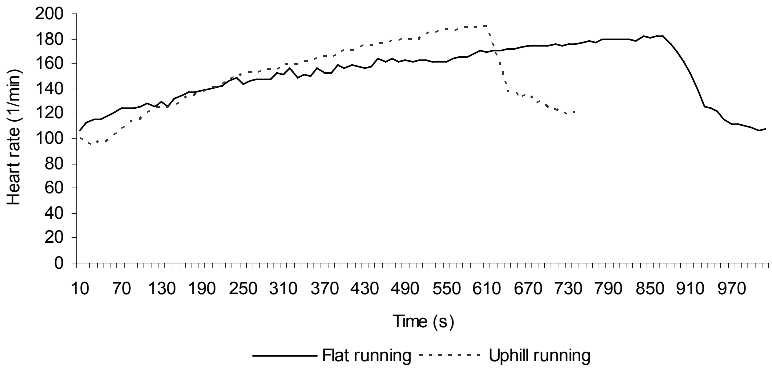

Fig. 2. Heart rate prior to, during and after flat and uphill running

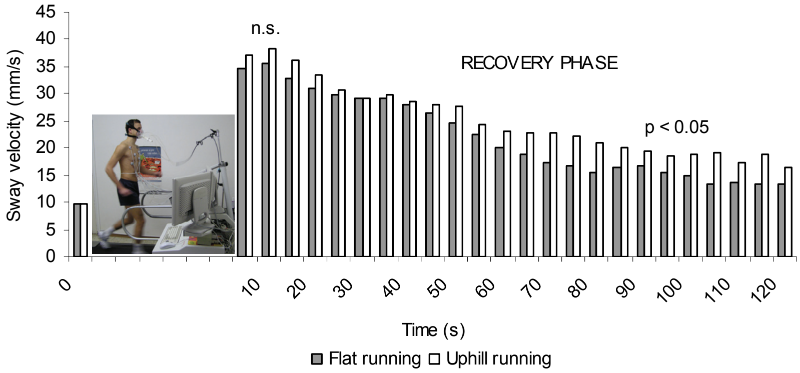

Fig. 3. Velocity of the centre of pressure prior to and after flat and uphill running

DISCUSSION

In spite of the longer duration of flat running possibly inducing slightly greater fatigue, there was a longer balance impairment after uphill running. Though the kinetics of sway velocity during an initial 50 seconds of recovery was similar, after that period its values declined by 40% for level running and by only 32% for upslope running. These differences in the speed of post-exercise balance readjustment may be ascribed to differences in the contraction mode of the working muscles.

As mentioned, a substantial percentage of the gait cycle is performed by eccentric contractions of the lower limb muscles (Inman et al., 1981). For upslope walking it is known that all three joints are flexed more at heel strike and extend more during mid-stance, when compared to level walking. These postural changes are consistent with the need to raise the limb for toe clearance and heel strike and then to propel the body up the incline, which would require muscle shortening during stance, particularly in the single joint knee and ankle extensors (Lange et al., 1996; Leroux et al., 1999).

It may be assumed that the association with muscle length changes, along with the subsequent effect on muscle spindle afferents and proprioceptive feedback to the muscle pattern generator. It is known that during concentric work, fusimotor drive is insufficient to compensate for muscle shortening, and spindle afferents become silent. In eccentric contractions, on the other hand, the stretch sensitivity of muscle spindles increases, which increases the activity in spindle afferents and increases muscle stiffness (Gandevia, 1998).

Such stiffness mechanisms could not only prevent sway deviations during upright stance (Corbeil et al., 2003) but may be also important in response to unexpected external perturbations (Winter et al., 1998). More specifically, during the lengthening (eccentric) contraction, stiffness has been found to be initially high (i.e., a large change in force for a small change in length) and then declined (Gillard et al., 2000; Rack, Westbury, 1974; Walmsley and Proske, 1981). This short-range stiffness is greater in type I compared with type II muscle fibers (Malamud et al., 1996), which are not greatly subject to fatigue. Slow-twitch fibers can be found in the m. soleus, whose activity correlates with the center of pressure displacement. This may in part explain the slightly smaller increase in sway velocity and its faster readjustment after flat running as compared to uphill running.

However, during running, eccentric contractions produce twice the tension per active muscle fiber compared with concentric contractions (Sargeant and Dolan, 1987), leading to intensive stimulation of the muscle spindles, tendon organs, joint receptors, and cutaneous mechanoreceptors on the sole. Thus, another explanation for differences in post-exercises balance impairment should come from the ground reaction forces. However, Lay et al. (2006) found that though during upslope walking the propulsive force of the anterior-posterior component increases, the resultant force was similar to that for level walking. In this case, output from cutaneous load sensors should be similar to that during level waking.

However, these authors also found that the support moment increased significantly during both upslope and downslope walking compared to the level: the increases were predominantly due to the increasing hip extensor moment during upslope walking, and to the increasing knee extensor moment during downslope walking. In addition, the hip and knee joint moment patterns showed significant differences from the patterns observed during level walking.

Although these findings suggest that slope walking requires movement control strategies different from those for level walking, we suppose that mainly the above mentioned peripheral factors related to the contractile apparatus might explain different postural sway responses to the examined exercise modes.

Such information can be of practical significance in situations where impairment of balance may affect the performance and/or increase risk of injuries. For instance, in sports such as the biathlon, where impaired postural stability resulting from prolonged cross-country skiing adversely affects the standing shooting performance (Hoffman et al., 1992), its readjustment to the pre-exercise level is considered as an important ability. This ability is also important for the elderly with coordination problems and those with changed gait pattern due to disease, injury or surgery of the lower extremities (Illyés and Kiss, 2005; Bejek et al., 2006; Illyés et al., 2006; Paróczai et al., 2006) in which even small changes in balance induced by exercise (e.g., walking) may increase risk of falling and subsequent re-injury. Since for these individuals is more important to maintain balance in dynamic conditions, the effect of exercise on its parameters should be investigated using dynamic posturography systems or a 3D biomechanical analysis (Psalman, 2008). Further studies are also needed to evaluate the effect of downhill running or walking on postural stability.

CONCLUSION

There is slightly higher postural sway with a slower readjustment to the pre-exercise level after upslope than flat running. Such longer balance impairment may be attributed mainly to a difference in the unique properties of predominantly concentric rather than eccentric contractions.

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ODGOVOR TELESNOG NJIHANJA NA MAKSIMALNO VEŽBANJE SA RAZLIČITIM FORMAMA MIŠIĆNE KONTRAKCIJE

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Studija upoređuje parametre ravnoteže nakon nagiba na tredmilu i trčanja po ravnom uključujući različite forme mišićne kontrakcije. Grupa od 14 studenata fizičkog vaspitanja (19.2 ± 2.9 godina, visina 180.0 ± 7.3 cm, težina 69.2 ± 8.4 kg) je učestvovala u različitim danima u dve etape vežbi na tredmilu. U oba slučaja, početni intenzitet od 5.6 km/h je povećan za 1.2 km/h svakog 1.5 minuta do maksimuma. Ipak tokom trčanja uz brdo nagib na tredmilu bio je 15%. Trajanje trčanja po ravnom je bilo duže u poređenju sa trčanjem pod nagibom, u proseku 10 i 14 minuta. Trideset sekundi pre i dva minuta posle vežbanja COP ubrzanje je registrovano na 100 Hz sa posturografskim sistemom FiTRO provere njihanja bazirano na dinamometričkoj platformi. Dok su vežbali i stajali na stabilografskoj platformi kardiorespiratorni parametri su praćeni sistemom udah-po-udah, sistemom Spiroergometrije CS 200. Kao što je i bila namera, nije postojala razlika u vrhuncu disanja nakon nagiba i trčanja po ravnom (149.3 ± 13.1 l/min i 146.7 ± 12.6 l/min). Isto tako, za vreme izvedenih vežbi dobijeni su slični srčani otkucaji (190.0 ± 11.1 bpm i 182.2 ± 8.9 bpm). Takođe brzina njihanja u početnom 5-sekundnom periodu oporavka nije se razlikovala nakon oba vežbanja (37.2 ± 3.8 mm/s i 34.7 ±3.1 mm/s). Ipak, njegovo duže prilagođavanje nivou pre vežbanja je uočeno nakon trčanja pod nagibom u poređenju sa trčanjem po ravnom. Ove razlike nakon oko 50 sekundi oporavka su bile značajnije ($p \leq 0.05$). U oba slučaja vrednosti se nisu vratile na osnovnu liniju unutar pregledanih dva minuta nakon vežbanja. Može se zaključiti da je telesno njihanje malo veće nakon trčanja pod nagibom, nego trčanja po ravnom, ali njegovo usaglašavanje na ono pre vežbanja je značajno sporije. Takvo duže pogoršavanje ravnoteže može da se pripiše samo razlikama u jedinstvenim osobinama predominantne koncentrične nego ekscentrične kontrakcije.

Ključne reči*: forma mišićne kontrakcije, trčanje po ravnom, telesna stabilnost, trčanje pod nagibom*