

Edit Nagy · Kalman Toth · Gabor Janositz
Gyula Kovacs · Anna Feher-Kiss · Lajos Angyan
Gyöngyi Horvath

Postural control in athletes participating in an ironman triathlon

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Abstract We studied the degree of dependence on vision of static postural control among ten male adult ironmen and ten healthy subjects (firemen, control group) who took part in regular physical activity, and the perturbations of equilibrium after prolonged exercise in ironmen. Static postural stability was measured during standing on a single-force platform alternating between eyes open and eyes closed. First, body sway was analysed on a force plate in both groups, and the athletes then took part in an ironman triathlon. The measurement was repeated after the race. The sway in both directions was subjected to spectral analysis. The frequency spectrum of the platform oscillations was calculated by fast Fourier transformation in the intervals 0–0.3, 0.3–1 and 1–3 Hz. The sway path in both directions and the total path were significantly lower in the ironmen than in the control group without vision, and the absence of visual control caused a significant increase in sway in both directions in the control group, but not in the ironmen. The frequency analysis revealed a higher level of stability in the medio-lateral direction with closed eyes. The

endurance race caused increases in both the total sway path only with closed eyes, and these changes were significant at higher frequency bands. These results indicate that ironmen are more stable and less dependent on vision for postural control than the control subjects, and the prolonged stimulation of the proprioceptive, vestibular and visual inputs in the endurance race causes a significant disturbance in postural control.

Keywords Fatigue · Exercise · Human · Postural sway · Triathlon

Introduction

The motor control of the body is dependent upon visual, vestibular and proprioceptive feedback, and the reflexive and voluntary muscle responses (Isableu et al. 1997; Johnston et al. 1998). The balance is actively controlled by the central nervous system (CNS), which calls into action the various relevant postural muscles, as and when needed (Nardone et al. 1990). During a quiet stance, little activity is normally required on the part of the postural muscles (Schieppati et al. 1994), thanks to the ability of the CNS to anticipate minimal body destabilisation. Accordingly, when any of these inputs is defective, the body sway increases and the muscle activity increases concurrently, in order to maintain balance (Dietz 1992). Apart from the role of possible alterations in the sensory inputs, some information exists as to other causes that may affect the control of body balance under specific physiological conditions.

Only a few studies have reported the postural control of sportsmen, and most of these studied sportsmen who needed special skills in balance control. Thus, it has been observed that professional dancers and gymnasts are significantly more stable and less dependent on vision for postural control than untrained subjects (Golomer et al. 1999; Vuillerme et al. 2001a). Nevertheless, gymnasts are particularly less dependent on visual cues than

E. Nagy · A. Feher-Kiss · G. Horvath (✉)
Department of Physiotherapy,
Faculty of Health Science,
University of Szeged, Temesvari krt. 31,
6726 Szeged, Hungary
E-mail: horvath@phys.szote.u-szeged.hu
Tel.: +36-62-544-971
Fax: +36-62-545-842

K. Toth · G. Janositz · G. Kovacs
Department of Orthopedics,
Jozsef Hollos County Hospital,
Kecskemet, Hungary

G. Horvath
Department of Physiology,
Faculty of Medicine,
University of Szeged, P.O. Box 427,
6701 Szeged, Hungary

L. Angyan
Institute of Human Movement Sciences,
Medical School, University of Pécs,
Pécs, Hungary

other sportsmen for maintaining balance in challenging postures. These results suggest that gymnasts and dancers can switch between visual and other sensory systems more efficiently, or they have a more sensitive sensory system as compared with other sports experts. However, both dancers and gymnasts have special skills, and their training develops proprioception so as to reduce the dependence on vision for postural control (Golomer et al. 1999; Vuillerme et al. 2001a, b). Ironmen are well-trained sportsmen who have a high level of practice in running, cycling and swimming. However, ironman training does not require special practice in balance, and therefore it might be supposed that ironmen do not differ significantly in postural control compared with healthy, physically active subjects. The first goal of the study, therefore, was to compare the postural control of ironmen with that of healthy subjects who partook in regular physical activity.

It is well known that the ironman triathlon is an ultra-endurance race, which causes significant changes in various physiological parameters. In fact, the rare experiments in which fatigue was induced by an ironman triathlon, a highly exhausting exercise for the whole body, studied cardiovascular alterations (Holtzhausen and Noakes 1995; Douglas et al. 1987, 1998; Rifai et al. 1999; Whyte et al. 2000), endocrine effects (Ginsburg et al. 2001), and energetic aspects (Laursen et al. 2002) only. Therefore, the second aim of our experiment was to examine postural control after an ironman triathlon race. For this purpose, we tested the changes in postural sway path and frequency oscillation that may be observed after the triathlon.

Methods

Subjects

Ten healthy subjects (control group) and ten ironmen were enrolled in the study. The control subjects were firemen who participated in different forms of physical activity (running, playing football) at least three times per week, but none were professional athletes. All the subjects gave their informed consent prior to participation in the study. We declare that the experiments comply with the current laws of our country.

Experimental procedure

Static postural stability was measured during standing on a single-force platform (Stabilometer, ZWE-PII) for 20-s periods. The platform allowed measurement of the displacement of the centre of foot pressure (sway path). Signals were amplified and sampled at 16 Hz via an analog-to-digital converter. Posturography was performed alternately with the eyes open (EO) and then with the eyes closed (EC), always starting with EO. During the EO test, the subject looked at a fixed

eye-level target at a distance of approximately 2 m. The subjects stood barefoot, with the feet positioned side by side with no space between them, and they were instructed to minimise postural sway. After the initial balance testing (pretest), the athletes took part in an ironman triathlon (3.8 km swimming, 180 km cycling and 42.195 km running; duration, 9–12 h). At the end of the race, all the ironmen reported a feeling of dizziness. Accordingly, the after-exercise series of trials on the stabilometric platform began about 15 min from the end of the exercise (post-test 1) and was repeated 5 min later (post-test 2). Since the control group did not take part in the race, they gave only baseline values (pre-test). The second determination after the race (post-test 2) was performed to observe signs of recovery in the postural sway parameters.

Data analysis

The first 4 s of the 20-s time series was regarded as an adaptation period and was discarded from the data analysis after the filtering processes. The data were low-pass filtered at 10 Hz, since most of the power of the signal was below 2 Hz (Soames and Atha 1982). The sway path in both directions (anterior–posterior, A/P; medio–lateral, M/L) and the total length of the sway were calculated via the formulae:

$$\text{Sway path} = \sum_{i=1}^{n-1} \sqrt{\{s_x(i+1) - s_x(i)\}^2}$$

and:

Total path

$$= \sum_{i=1}^{n-1} \sqrt{\{s_x(i+1) - s_x(i)\}^2 + \{s_y(i+1) - s_y(i)\}^2}$$

where n is the total number of samples, i is the sample number, s_y is the A/P sway and s_x is the lateral displacement of the centre of pressure. These parameters reflect the amount of activity required to maintain stability.

The sway in both directions was subjected to spectral analysis. The frequency spectrum of the platform oscillations was calculated from 0 to 3 Hz by fast Fourier transformation. The postural performance was calculated from the power spectrum in the intervals 0–0.3, 0.3–1 and 1–3 Hz. This method is a modification of the spectral analysis methods of Golomer et al. (1994) and Openheim et al. (1999). These results suggest that the low-frequency band is linked with visual control, the middle-frequency band is sensitive to vestibular and somatosensory information, and the high frequencies reflect the proprioceptive control and the muscle activity (Golomer et al. 1999). A decrease in this averaged mean power indicates an increase in postural stability. All the data were subjected to appropriate analysis of variance

in order to make comparisons between the groups and the experimental situations, which constituted the independent variables. In the first experiment, a three-factor analysis of variance was used and the factors were sway direction, subject type and visual condition. In the second analysis, the factors were sway direction, visual condition and time. The post-hoc test was the least significant difference multiple comparisons test. A 0.05 level of significance was adopted throughout the data analysis.

Results

The age [controls, 33 (1.3); ironmen, 33 (2.4) years], body mass [controls, 78 (2.8); ironmen, 74 (2.3) kg] and body height [controls, 175 (1.5); ironmen, 175 (2.2) cm] did not differ significantly between the two groups.

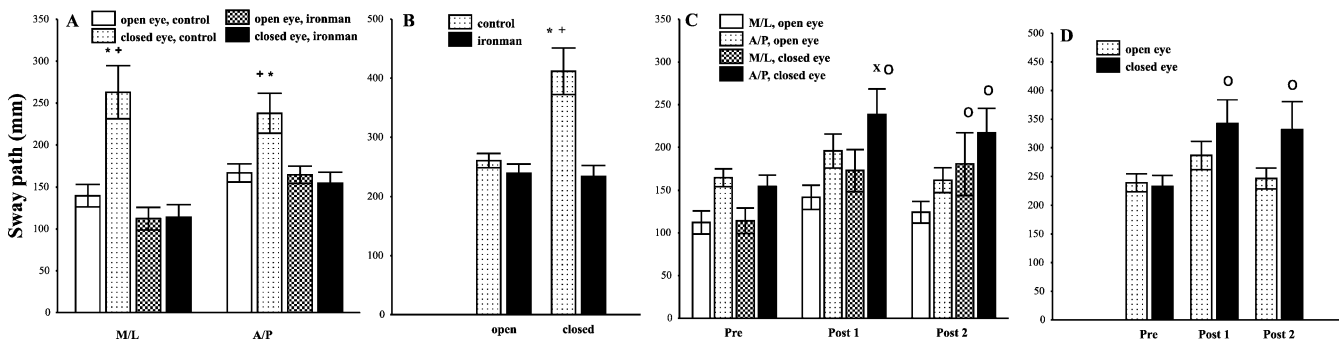
The sway path in both directions and the total path were significantly lower in the ironmen than in the control group without vision (Fig. 1A, B). The absence of visual control caused a significant increase in sway in both directions in the control group, but not in the ironmen.

The frequency analysis also revealed significant differences between the two groups. At low-frequency band (0.1–0.3 Hz), there were significant differences between the two groups in some respects, i.e. the ironmen showed a lower amplitude in the M/L direction in the EC condition as compared with the control group (Fig. 2A). Furthermore, the absence of visual control slightly increased the power of frequency in the control group, whereas the eye status did not influence the power for the ironmen. As regards this frequency band in the A/P direction, there was no significant difference between the two groups in either visual condition. Surprisingly, in the ironmen, the sway frequency power in the M/L direction was significantly lower than that in the A/P

direction in both visual conditions, while the control group did not exhibit these differences. At the middle frequency band (0.3–1 Hz), there were significant differences between the two groups in the M/L direction in both visual conditions, i.e. the ironmen showed a lower power of sway frequency (Fig. 2B). While the visual condition did not influence the power in the ironmen, the absence of visual control significantly increased the sway power in the control group. As regards the A/P sway frequency, there was a significant difference between the two groups in the EC condition. Furthermore, the A/P sway frequency power was significantly higher than the M/L power in the EC condition in the ironmen, while the control group did not display these differences. At the high-frequency band (1–3 Hz), there were significant differences between the two groups, again in the M/L direction in both visual conditions, i.e. the ironmen had a lower power of sway frequency (Fig. 2C). While the visual condition did not influence the power in the ironmen, the absence of visual control significantly increased the sway power in this direction in the control group. As regards the A/P sway frequency, there was a significant difference between the two groups in the EC condition. In the ironmen, the M/L sway frequency power was significantly lower than the A/P power in the EC condition, while the control group did not show these differences.

The race caused a temporary, slight increase in the sway path in both directions in both visual conditions, and this increase was significant in the A/P direction with the EC condition (Fig. 1C). Similarly, the increase in the total path was significant in the EC condition after the race (Fig. 1D). As regards the spectral analysis, at the lowest frequency band (0.1–0.3 Hz), the race did not cause any significant change in the power (Fig. 2D). However, it was observed that, in the first measurement, the A/P and M/L powers were very similar in both visual conditions, which is in contrast with the baseline. At the middle-frequency band (0.3–1 Hz), the race caused a significant increase in the power in the A/P direction in the EC condition as compared with the baseline value (Fig. 2E). Furthermore, in the second determination, the power increased significantly in both directions without visual control. At the high-frequency band (1–3 Hz), in the first measurement after the race, a significant difference was observed between the two directions in the EC condition. In the second determination, the absence

Fig. 1 Mean (SEM) sway path in both directions (A) and total sway path (B) for the two groups. The effects of the triathlon on the sway at both directions in ironmen (C) and on the total sway path (D). Statistically significant differences ($P < 0.05$) in comparison with the ironmen group (+), in comparison with the basal value (o), in comparison with the medio-lateral (M/L) direction (x) and in comparison with the open eye (*). A/P Antero-posterior direction



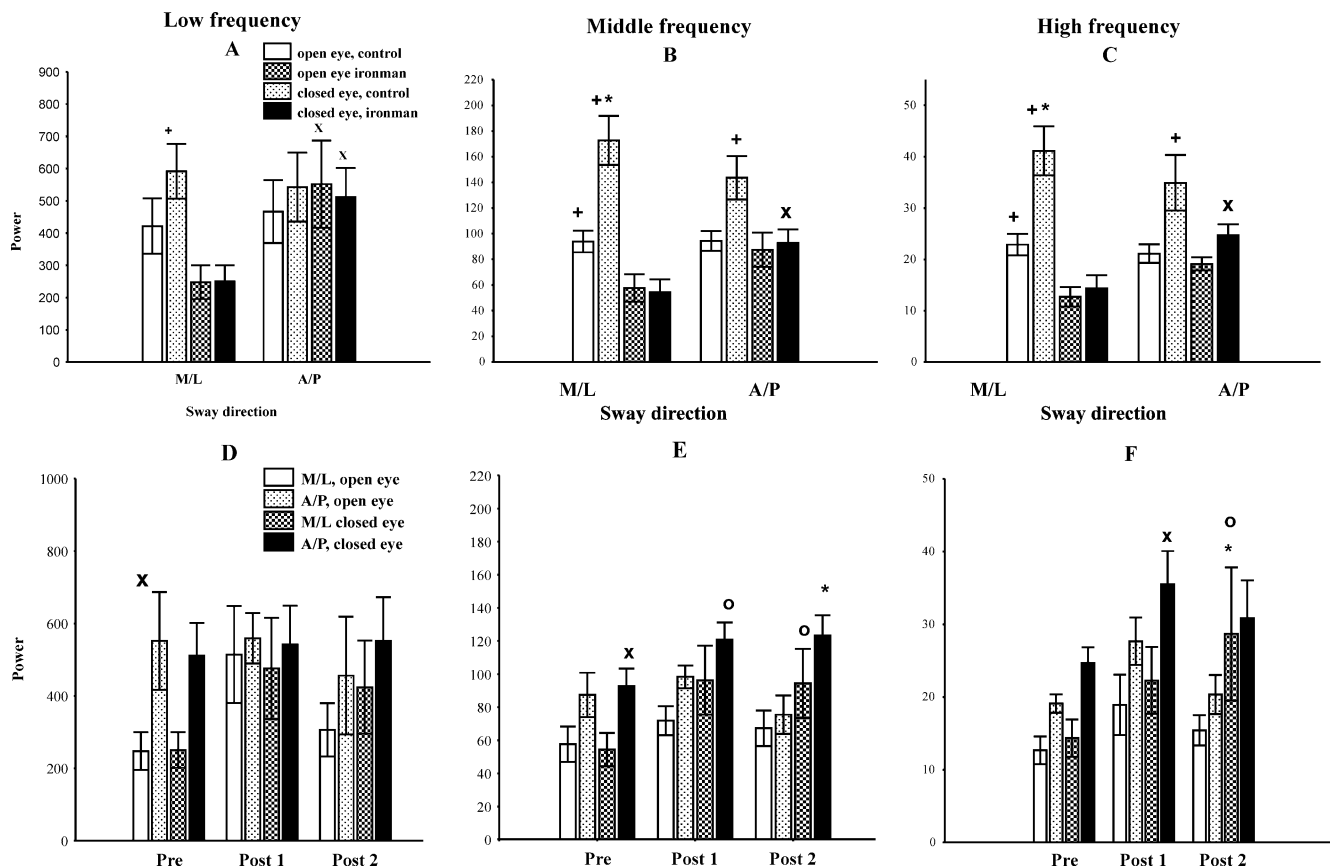


Fig. 2 Mean (SEM) spectral energy at different frequency bands for the two groups (A–C). The effects of the triathlon on the spectral energy at different frequency bands in ironmen (D–F). Statistically significant differences ($P < 0.05$) in comparison with the ironmen group (+), in comparison with the basal value (o) in comparison with the M/L direction (x) and in comparison with the open eye (*)

of visual control significantly increased the power in the M/L direction, and in this direction the change was also significant relative to the baseline (Fig. 2F).

Discussion

The main findings of the present study were that the ironmen were significantly more stable and less dependent on vision for postural control than subjects who partook in regular physical activity. Furthermore, the endurance race caused significant increases in both the sway path in the A/P direction with EC. The second post-exercise trials indicated a trend in the decrease of postural changes. The frequency analysis also revealed some new findings, which were not significant in sway-path analysis. Thus at the low-frequency band, there were significant differences between the A/P and M/L power in ironmen in both visual conditions, but not in the control group, suggesting that this band might not be linked only with visual control. This difference could be observed in this group at all frequency bands with

EC, indicating a higher level of motor control in the M/L direction.

Only a few studies have investigated the physiological changes in ultra-endurance triathletes. However, to date, no data are available concerning the postural control of ironmen. The fact that ironmen have a higher level of stability in the EC condition suggests that the postural control of ironmen is less dependent on vision. For the control group, vision made a significant contribution in reducing the frequency oscillations, but this effect could not be observed in the ironmen. However, it is very difficult to discuss and analyse the results of the changes in the power of frequency. Several studies indicated that different neurophysiological circuits underlie the various frequencies of body sway for regulation of the upright posture. The frequency content of postural sway has been reported to contain over 90% of the total energy below 2 Hz, and it is normally distributed as regards events such as respiration and heart beat (Soames and Atha 1982). There are some examples for the subdivision of the power spectrum in frequency windows. Thus, the total energy of the power spectrum was divided into three bands by Golomer et al. (1999) (0–0.5, 0.5–2 and 2–20 Hz) in order to facilitate the attribution of the observed values to the main regulation of the neuronal loops. It was observed that vision made the largest contribution to reducing the frequency oscillations for all bands, i.e. results in accord with those in our control group. Furthermore, it has been found that equilibrium

training (dancing) significantly decreases the spectral energy at all frequency bands (Golomer et al. 1997). Others have analysed different frequency bands, i.e. 0–0.1, 0.1–0.5, 0.5–1 and >1 Hz (Oppenheim et al. 1999) and produced results suggesting that the low frequencies are linked with visual control, the medium–low frequency band with vestibular reflexes, the medium–high frequencies with somatosensory activity, and the high–frequency band with the function of the CNS. However, the distribution of frequency oscillations to the 0.01–0.7, 0.7–1 and >1 Hz bands revealed that the diabetic proprioceptive deficit led to multiplanar destabilisation at the medium–high frequency range, while the labyrinth deficit in nondiabetic patients caused lateral destabilisation at all frequencies (Giacomini et al. 1998). In a pilot study, the frequency power changes after work demonstrated that the spectral power at the low-frequency band (0.1–0.25 Hz) was significantly influenced by shift work (Kohen-Raz et al. 1996). Thus, there is no universal agreement as to the importance of this index or as to whether it is specific in identifying alterations in the postural control systems; however, our data suggest that the general increase of power spectrum after fatigue might be nonspecific and merely connected with the increase in sway. Nevertheless, some hypotheses appear to be generally accepted: visual information dominates, proprioception affects mainly A/P oscillation, relatively low-frequency body oscillation is affected by vestibular input, while higher frequency oscillations are controlled by proprioceptive information (Giacomini et al. 1998). Thus, our spectral analysis results reveal that the visual control did not change the power of frequency at any band in the ironmen. Furthermore, the ironmen were more stable in the M/L than in the A/P direction, which might be due to the excellent hip control (Winter et al. 1996) or highly effective proprioception (Giacomini et al. 1998). We propose that all of these differences in equilibrium may be due to a higher level of skill in ironmen. The significantly lower power at all frequency bands suggests that not only the visual, but also the vestibular and proprioceptive information processes are more effective in ironmen.

Surprisingly, the endurance race caused only a slight change in the sway path. The only significant increase was observed in the A/P direction, suggesting a decreased balance, mainly in the ankle balance (Winter et al. 1996). These minor changes might be due to the practice in this type of exercise or muscle stiffness (Vuillerme et al. 2000). However, the frequency analysis revealed several significant changes as compared with the pretest values, indicating that this method is a more sensitive means of exploring the changes in the postural control.

Over the last decade, the effect of physical exercise on body balance has received increasing attention. Several studies have shown that fatigue, which is typically an internal perturbation, may alter this function (Nardone et al. 1997; Johnston et al. 1998; Vuillerme et al. 2001a, b; Derave et al. 2001, 2002). All these studies found that muscular fatigue caused a temporary destabilising effect,

i.e. an increase in postural sway. Although there seems to be overall agreement that strenuous exercise adversely affects stability during a subsequent quiet stance, much uncertainty and disagreement remains concerning the modalities of this effect. Furthermore, most of these studies investigated healthy normal subjects who do not take part in extreme sport activities. Thus, the effects of isokinetic fatigue of the ankle plantarflexors and dorsiflexors have been determined in healthy subjects (Yaggie and McGregor 2002). It is well known that the fatigue caused by several kinds of physical activities significantly influences the postural control (Nussbaum 2003). Fatigue is often characterised by an impaired performance involving both motor and sensory processes. The main cause of these changes should be the muscle fatigue. A number of data demonstrate that both ankle and calf muscle fatigue cause a significant increase in postural sway (Yaggie and McGregor 2002; Vuillerme et al. 2002), and strenuous exercise (treadmill walking for 25 min) causes a significant increase in body sway in both EO and EC conditions with a 15-min recovery (Nardone et al. 1998). Furthermore muscle fatigue could impair the balance between anterior and posterior muscles on the leg, e.g. m. rectus femoris and m. semi-tendinosus, and also the paravertebral muscles (Nyland et al. 1997; Ebenbichler et al. 2002). These effects could also contribute to the increased body sway, but further studies are needed to demonstrate this. Some studies have shown that 5 h of exhausting exercise impairs the contractile properties, the excitability (at the neuromuscular level) and the central drive of the muscles for at least 1 h (Millet et al. 2002; Lepers et al. 2002). These results agreed with ours, because the postural changes after the exhausting race were significant after 15–20 min, but there was a trend to recovery.

However, apart from fatigue, additional factors may also contribute to reduced postural stability following exercise. It has been demonstrated that the visual input in postural control is affected by exercise (Derave et al. 2002) and subjects make less effective use of vestibular input (Lepers et al. 1997). These results suggest that running tends to disturb the postural stability, possibly because of the more excessive head movement and disturbance of the vestibular and visual information centres. It has been claimed that an impaired balance following running is also related to the conflict of information between the somatosensory and visual inputs during treadmill running (Hashiba 1998). After modification of the sensory inputs available, individuals need to redefine the respective contributions of the different sources of sensory information in order to regulate posture. Therefore, after the race both the afferent and efferent pathways and the central part of the postural control will be influenced.

Internal masses in motion within the body, such as those associated with the cardiovascular system, with the blood mass transient movement at each heart-beat, and with ventilation, have seldom been taken into consideration. These masses in motion contribute, by

definition, to the whole-body centre of mass displacement, and thus to the ground reactions. There have been reports about the effects of respiration and cardiac function on postural sway. These data suggest that respiration is a significant input for postural control (Bouisset and Duchene 1994). The magnitude of the respiratory contribution to sway is approximately constant over the normal range of respiratory rates and is linearly related to the respiration amplitude, indicating that the coherence between the respiration and the centre of pressure is low during quiet breathing, but is increased when the respiration is increased (Hunter and Kearney 1981; Hodges et al. 2002). As regards the effects of the cardiac cycle, it has been reported that the displacement of the centre of pressure during a cardiac cycle would be 0.5–1 mm (Conforto et al. 2001). However, it seems that the heart rate is not significantly correlated with the sway measurements (Kincl et al. 2002). Finally the dehydration that always occurs after the triathlon could also impair the postural control (Holtzhausen and Noakes 1995; Gauchard et al. 2002). Since we did not determine the heart rate, breathing rate and the extent of dehydration during and after the race, we could not determine the correlation of these parameters. However, we presume that the increased frequencies of the cardiorespiratory parameters and dehydration could also influence the postural sway after the race.

Hence, there were several potentially important limitations in this study, because we did not determine the above-mentioned parameters. From these data, therefore, it is difficult to determine the exact causes of the impairment of the postural control. We suggest that the decrease in postural control after the race might be due to the muscle and neuromuscular fatigue, the sensory and the central impairment, the dehydration and the cardiorespiratory changes, because these effects are probably present simultaneously, and the net result depends on their sum.

In conclusion, we have demonstrated that the exhaustive race significantly affects the ability of ironmen to maintain balance. Further studies of muscular activity, heart and breathing rates, and degree of dehydration, in parallel with posturography, are needed for a better understanding of the changes in postural control observed following the ironman triathlon. It could be also interesting to determine to what extent the postural disturbance could affect the stance in the last part of the triathlon.

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