DO YOUNG HEALTHY ATHLETES MAINTAIN THEIR STANDING EQUILIBRIUM BETTER IN BARE FEET ?

Virgilio F. Ferrario, Chiarella Sforza, Nicola Fragnito, Luciano Mauro, Franco Mauro,
Università degli Studi di Milano, Milano, Italy

INTRODUCTION: The performance of almost all individual and team sports depends, among other things, on the maintenance of equilibrium. The athlete is challenged by the force of gravity (for instance, in gymnastics), by an unstable (as in windsurfing) or extremely reduced (as in ice skating) support, by external forces (for instance, in contact sports), and should counterbalance the perturbing element by using the appropriate neuromuscular strategies (Horak and Nashner, 1986). Several approaches have been devised to study and model the phenomena: a biomechanical or “morphological” approach which measures the movements of the body segments as well as of the body center of gravity, an electromyographic approach which quantifies the activity of the muscles most involved in the response, and a “force plate” approach which assesses the movements of the center of foot pressure relative to the ground (Alexander, 1994; Ferrario et al., 1996; Horak and Nashner, 1986; Puleio, 1997; Soutas-Little et al., 1992).
Most of the investigations focused on the lower limbs, standardized the position of the trunk and upper limbs, and analyzed the effect of modifications of the support surface (dimensions, flexibility, stability) and foot position (bipedal, unipedal, tandem) (Alexander, 1994; Puleio, 1997). These studies are usually performed under laboratory conditions with barefooted subjects, the use of shoes being infrequently reported (Roland et al., 1995). On the contrary, in sport performance the use of shoes is more the rule than the exception (such as in gymnastics), and the effect of wearing sport shoes on the maintenance of equilibrium has never been tested.
The aim of the present study was to assess the influence of sport shoes on the maintenance of equilibrium while standing on a tilting platform. In this first report, the analysis will focus on the global result, independently of the neuromuscular strategy adopted by the athletes.

METHODS: Ten young healthy athletes (five men, five women, Table 1) aged 19-25 years, with normal or corrected to normal vision, volunteered for the study. They were without a history of vestibular, proprioceptive or postural problems. They all were students of the Istituto Superiore di Educazione Fisica della Lombardia, and were practicing several kinds of sports (athletics, gymnastics, snowboard) at the amateur level.
The subjects were asked to stand on a 65x65 cm wooden platform that tilted on a steel half sphere with a 25 cm radius, and instructed to keep the platform as horizontal as possible over a 30 s test. Their feet had to be positioned at least 24 cm apart, with parallel medial borders. No particular instruction was given for the positions of arms, trunk or legs, and the subjects were free to adjust the relative positions of body segments according to the maintenance of equilibrium. The task was repeated three times with the subjects barefooted, and three times with the

subjects wearing their own (habitual) sport shoes. To avoid the effects of fatigue, each test was performed with at 30 minute intervals, and to avoid any learning effects, the order of the six tests was randomized among the 10 subjects.

A 2-cm spherical retro-reflective marker was positioned on each of the four corners of the platform. During the test, the three-dimensional coordinates of the centers of gravity of the markers were automatically collected using a motion analyzer system (ELITE, BTS, Milan, Italy). The system consists of four high resolution infrared sensitive CCD video cameras coupled with a video processor. The cameras were positioned at the four corners of the 7x7 m area surrounding the platform, at 3.30 m from the ground, and a stereoscopic view of the markers was thus obtained. The video processor detects the marker coordinates as seen by each camera, corrects electronic and optical distortions, integrates the four sets of data for each marker, and supplies the actual metric x, y, and z coordinates (Ferrario et al., 1997).

The system has a sampling ratio of 100 Hz, and 3000 sets of data were therefore available for each subject and test. For each set of data, original software calculated the movement of the platform versus the ground (reference) in the last 20 s of each test. From the center of gravity of the platform (origin of axes), the directrix of the plane was computed, and its antero-posterior and laterolateral (left-right) inclinations were further analyzed.

Univariate analysis was used to compute the instantaneous angular velocity (°/s) of the directrix during the trial. Bivariate analysis was used to calculate the area of the confidence ellipse of the directrix at length 1 (proportional to the variability of the oscillation), and the distance between the origin of the axes and the center of the ellipse (modulus, which is proportional to the mean oscillation). Bivariate analysis allows a more correct and complete analysis of data defined by couples of coordinates because it evaluates the anteroposterior and left-right displacements at the same time.

Table 1. Characteristics of the analyzed subjects.

Subject	Sex	Age (ys)	Height (cm)	Weight (Kg)	Shoe size
PA	M	24	175	66	41
RA	M	22	162	56	40
BF	M	25	169	57	39
CS	M	20	169	67	43
IC	M	24	189	90	48
GS	F	21	174	67	40
MV	F	20	161	55	38
SR	F	20	163	69	40
PM	F	20	160	49	37
GL	F	19	161	48	41
Mean		21.5	168	62	
SD		2.1	11.8	8.7	

Mean values were computed for the barefooted and sport shoes conditions (three repetitions for 10 subjects for each condition), and compared using Student's t for independent samples. Significance was set at 5% ($p \leq 0.05$).

RESULTS: Overall, all the athletes performed well in their three repetitions of the two test conditions. No errors were scored in the barefoot condition; on the contrary, in the sport shoe condition five trials (out of 30) had to be repeated because the subject lost his/her equilibrium and fell down before the end of the test.
On average, when barefooted, the subjects showed a significantly smaller area of oscillation (i.e., the platform movement was less variable) and smaller angular velocity than when wearing their habitual sport shoes (Table 2). Consistent (but not significant) modifications were found in the modulus values. Neither gender differences, nor effects of age, body weight, standing height or shoe size were found.

Table 2. Mean values (and SD) computed in ten young athletes (three repetitions each) compared by Student's t for independent samples.

	Barefoot	Shoe	p
Velocity (°/s)	7.43 (1.01)	8.38 (0.91)	<0.05
Ellipse area	116.84 (37.09)	198.57 (110.45)	<0.05
Modulus	2.55 (1.53)	2.91 (0.96)	ns

DISCUSSION: The present investigation analyzed the effect of wearing sport shoes on the maintenance of equilibrium as compared to a standard barefoot condition. The test devised, standing on a tilting platform, stressed the athletes with an ever-changing rigid surface, and was chosen to emphasize any possible difference between the two situations. The results showed that young healthy amateur athletes maintained their equilibrium better if barefooted. Sport shoes, which are almost always worn during sport performance, seemed to delay the necessary neuromuscular strategies, and the subjects had more difficulties in maintaining the platform horizontal.
The two variables that best discriminated between the two test conditions were the instantaneous angular velocity of the directrix of the plane, and the area of the confidence ellipse of the directrix at length 1 (Table 2). While it has already been reported that the sway velocity may be a more sensible index than the average deviation (Starck et al., 1993), the use of bivariate analysis in both dynamic and static evaluations of posture and equilibrium is rare (Ferrario et al., 1996). Instead of calculating separate means and standard deviations for the anteroposterior and left-right oscillations, this analysis provides a unique area of oscillation which is of easier comprehension and comparison between cases.
The present study used a somewhat different methodological approach to the biomechanical analysis of equilibrium. Instead of measuring the subject, an optoelectronic system detected the three-dimensional coordinates of the center of gravity of the platform, and the analysis was limited to the platform movement relative to the ground. Therefore, the global result of the test, independently from the neuromuscular strategy adopted by the athletes, was the object of interest. Further investigations could also analyze the movements of the body segments, and estimate the motion of the body center of gravity by placing similar markers on selected body landmarks (Ferrario et al., 1997; Gu et al., 1996).

CONCLUSIONS: The proprioceptive receptors of the foot and ankle seemed to work faster and more efficiently in barefooted young athletes, allowing a better maintenance of posture, with smaller oscillations in the horizontal plane.
It has to be mentioned that the analyzed athletes were all practicing sport at the amateur level, and none of them was a specialist or had particularly been trained for equilibrium. We are currently investigating elite athletes practicing different individual and team sports, where the equilibrium may play a different role in the global performance. If the present preliminary results are confirmed, a specific equilibrium training wearing sport shoes may be proposed to the athletes. An important side effect could be a reduction of traumatic sport injuries.

REFERENCES:
Alexander, N. B. (1994). Postural Control in Older Adults. *Journal of the American Geriatric Society* **42**, 93-108.
Ferrario, V. F., Sforza, C., Schmitz, J. H., Taroni, A. (1996). Occlusion and Centre of Foot Pressure Variation: Is There a Relationship? *Journal of Prosthetic Dentistry* **76**, 302-308.
Ferrario, V. F., Sforza, C., Poggio, C. E., Schmitz, J. H., Tartaglia, G. (1997). A Three-Dimensional Non Invasive Study of Head Flexion and Extension in Young Non-Patient Subjects. *Journal of Oral Rehabilitation* **24**, 361-368.
Gu, M. J., Schultz, B. A., Shepard, N. T., Alexander, N. B. (1996). Postural Control in Young and Elderly Adults When Stance is Perturbed: Dynamics. *Journal of Biomechanics* **29**, 319-329.
Horak, F. B., Nashner, L. M. (1986). Central Programming of Postural Movements: Adaptation to Altered Support-Surface Configurations. *Journal of Neurophysiology* **55**, 1369-1381.
Puleio, C. (1997). Può l'analisi posturale discriminare l'abilità di equilibrio di giovani ginnaste? *Coaching and Sport Science Journal* **2,3**, 3-7.
Roland, N. J., Smith, C. A., Miller, I. W., Jones, A. S., Lesser, T. H. (1995). A Simple Technique to Measure Body Sway in Normal Subjects and Patients with Dizziness. *Journal of Laryngology and Otology* **109**, 189-192.
Soutas-Little, R. W., Hillmer, K. M., Hwang, J. C., Dhaher, Y. Y. (1992). Role of Ground Reaction Torque and Other Dynamic Measures in Postural Stability. *IEEE Engineering in Medicine and Biology* **December**, 28-31.
Starck, J., Pyykko, I., Aalto, H., Pekkarinen, J. (1993). Measurements of Postural Stability: Development of a Force Platform and Some Excitation Systems. *Medical Progress through Technology* **18**, 209-215.