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ORIGINAL ARTICLE

Assessment of body plantar pressure in elite athletes: an observational study

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Abstract An intense program of physical activity, typical of elite athletes, results in a series of modifications of the posture that in a short period of time can have a negative impact on both their health and performance. These negative effects can be prevented and corrected by an integrated approach that encompasses anthropometry and posture evaluation. The aim of this study is the assessment of the anthropometric and postural parameters of elite athletes of different sports specialities to identify discipline(s) potentially associated with unbalanced postural attitudes. Height, weight, body mass index, stabilometric analysis, foot load, and center of pressure distribution were evaluated to identify which parameters are mainly correlated with postural aspects in professional athletes compared to amateur, age-matched subjects. We found a permanently unbalanced postural attitude in rugby players, skiers, and judokas, which are not, by definition, asymmetric sport disciplines. On the contrary, motorcyclists showed an overall balanced load distribution, probably due to the absence of any special performance required from lower limbs, potentially forcing a specific postural shape. This data is the basis to identify anthropometric and postural parameters mostly modified in different sport disciplines, which need to be always monitored to counteract the establishment of sport-specific imbalances.

Keywords Athletes · BMI · Foot pressure · Anthropometry · Sport

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Introduction

The relationship between balance ability and sport injury risk has been established in many cases, but the relationship between balance ability and athletic performance in both genders is less defined [1–3]. It is well-known that stresses greater than normal induce physical changes in biological tissues. For athletes, sport participation induces an increased strain in soft and bony tissues typically resulting in tissue adaptations, leading to increased strength and endurance. The laterality of particular sports has been linked to asymmetrical adaptations in bone and muscle girth, as well as flexibility and strength [4, 5]. For sports requiring repetitive throwing or striking (with implement) actions of the dominant limb, the implication has been

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musculoskeletal tissue adaptations in the overused limb resulting in bilateral skeletal asymmetries in the athlete [4, 5]. Much of the literature on asymmetrical skeletal adaptation due to sporting participation focuses on the upper-limb throwing athletes, and seemingly little research has been conducted on pelvic or lower-limb asymmetries in otherwise healthy athletes.

Furthermore, quantitative information regarding the body weight distribution on foot and balance ability is sparse, and in particular, no such study has compared athletes of different sports.

Based on the available data from cross-sectional studies, it is currently accepted that gymnasts tend to have the best balance ability, followed by football players, swimmers, and basketball players [1, 6].

There are some sports, such as rifle shooting, soccer and golf, where elite athletes were found to have superior balance ability compared to amateurs, but this was not found to be the case for alpine skiing, surfing, and judo. Balance ability was shown to be significantly related to rifle or archery shooting accuracy, ice hockey maximum skating speed, and simulated luge start speed, but not for baseball pitching accuracy or snowboarding [1, 6]. Prospective studies have shown that the addition of a balance training component to the activities of recreationally active subjects or physical education students resulted in improvements in vertical jump, agility, shuttle run, and downhill slalom skiing [1, 6, 7]. A proposed mechanism for the enhancement in motor skills from balance training is an increase in the rate of force development [1, 6, 7]. However, there is limited data on the influence of balance training on motor skills of elite athletes, with few exceptions [7, 8].

Balance ability was related to competition level for some sports, with the more proficient athletes displaying greater balance ability. There were significant relationships between balance ability and a number of performance parameters. Evidence from prospective studies supports the notion that balance training can be a worthwhile addition to the usual training of non-elite athletes to enhance specific motor skills, but not in place of other conditioning such as resistance training [1, 6–11].

The purpose of this study was to measure the plantar pressure distribution and body posture of elite athletes of different disciplines (rugby, biking, skiing, and judo) in comparison to amateurs, and to observe, if any, differences in anthropometric parameters that could influence balance ability.

Methods

Subjects

Twenty-nine male elite athletes from Italian rugby league, 29 international level bikers, 10 elite national team skiers and 10 national team judokas were recruited and gave informed consent to their involvement in this study.

A similar number of age-matched individuals practicing in the same sports at an amateur level in local centers of sport leisure and clubs were taken as controls. Participants were free of neuro-musculoskeletal injury at the time of the assessment. Table 1 shows subject information and anthropometric details for each group.

Anthropometric measurements

Anthropometric measurements were focused on BMI, calculated as body weight divided by squared height (kg/m^2). Body weight and height (without shoes) were measured wearing minimal clothing at the nearest 0.1 kg and 0.1 cm, respectively. Measurements were obtained in the morning. Parameters were routinely measured twice by two different trained technicians, and the mean was calculated.

Plantar pressure analysis

Plantar pressure was collected using a PoData capacitive pressure distribution system (Chinesport, Udine, Italy) integrated with a GPS 400 software [12]. This posture analysis system is made up of a number of units and a software that makes it possible to acquire images for body part measurements, as well as information concerning

Table 1 Anthropometric parameters of studied subjects

	Control (amateur athletes)		Rugby players		Bikers		Skiers		Judokas	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
N	71	–	29	–	29	–	10	–	10	–
Age (year)	26.7	5.9	25.0	4.0	25.2	5.0	23.7	4.9	28.6	7.5
BMI (kg/m^2)	22.5$^{b, d}$	1.1	30.0$^{a, c, d, e}$	3.1	22.3$^{b, d}$	1.8	24.4$^{a, b, c}$	2.6	25.8^{b}	2.2
Ht (cm)	174.8$^{b, d}$	3.1	180.7$^{a, c}$	5.9	173.3$^{b, d}$	5.0	182.6$^{a, c}$	4.0	175.5	5.3
Wt (kg)	74.5$^{b, d}$	9.8	98.1$^{a, c, e}$	12.7	68.1$^{b, d}$	9.6	87.7$^{a, c}$	8.1	79.4^{b}	10.2

N number of subjects, *BMI* body mass index, *Ht* height, *Wt* weight

[a] $p < 0.05$ versus amateur athletes, [b] $p < 0.05$ versus Rugby, [c] $p < 0.05$ versus Bikers, [d] $p < 0.05$ versus Skiers, [e] $p < 0.05$ versus Judoka

weight distribution, barycenter, and stability of the patient being examined, and it was used as per manufacture's instructions [12]. Preliminary optimization of the measurement conditions (pertaining to the time interval between shoes removal and test starting, characteristics of the surface while waiting without shoes (hard or soft), temperature of the testing platform) was performed, and all these parameters remained consistent during all measurements. Static plantar pressure values were collected in normal orthostatic position held for around 1 min. Before data acquisition, subjects were allowed adequate time to get used to the platform. The participants were instructed to stand upright facing forward normally.

Foot pressure was analyzed on three anatomical regions of interest (first and fifth metatarsal heads and heel, in both left and right foot), according with the standard literature [13–15]. Percentage of body weight distribution was calculated for each area, and measured body center of pressure (COP) was compared with the theoretical one [12–15]. Body COP deviation from theoretical reference was measured both on the anterior-posterior and latero-lateral axes [6, 12–15].

Statistics

The variables were compared between the groups using One Way Anova and Bonferroni *t* test for multiple comparisons. *t* test for independent or correlated samples was used when indicated. Results are expressed as means ± SD. Chi-square analysis was used for body COP deviation from theoretical reference both on the anterior-posterior and latero-lateral axes. All the statistical tests were performed at the 0.05 *p* value.

Results

Anthropometry

Rugby players were found to have a significantly higher BMI than all the other subjects (30.0 ± 3.1), as expected. Bikers showed significant differences in BMI, height, and weight only when compared with rugby players and skiers. The group of judokas displayed significant differences in terms of BMI and weight as compared to the rugby players (Table 1).

Plantar pressure

A detailed evaluation of anterior and posterior load distribution on the foot was performed, analyzing weight burden on the head of the first and the fifth metatarsal bones and, for the posterior support, on the heel bone. Significant

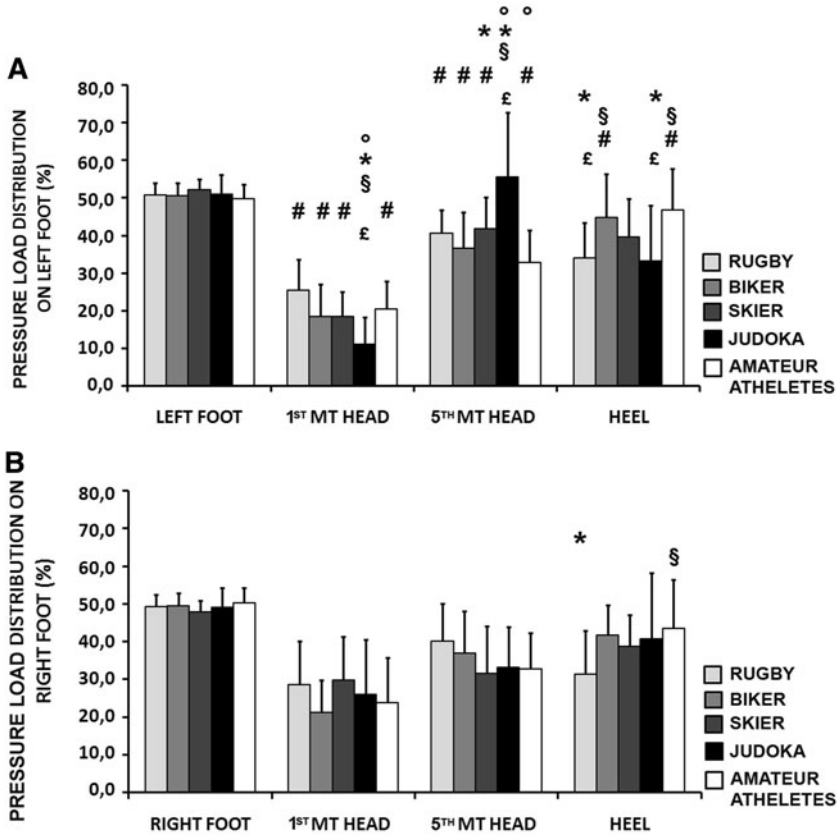

Fig. 1 Pressure load distribution on feet in all cohorts. **a** Percentage of pressure load distribution on left foot. **b** Percentage of pressure load distribution on right foot. The cumulative weight on left foot (*left foot*) or right foot (*rrght foot*) and its distribution on the three points for static support were analyzed: first metatarsal head (*1st MT head*), fifth metatarsal head (*5th MT head*) and heel (*heel*). $p < 0.05$ § versus Rugby; £ versus Biker; ° versus Skier; # versus Judoka; * versus controls (*amateur athletes*)

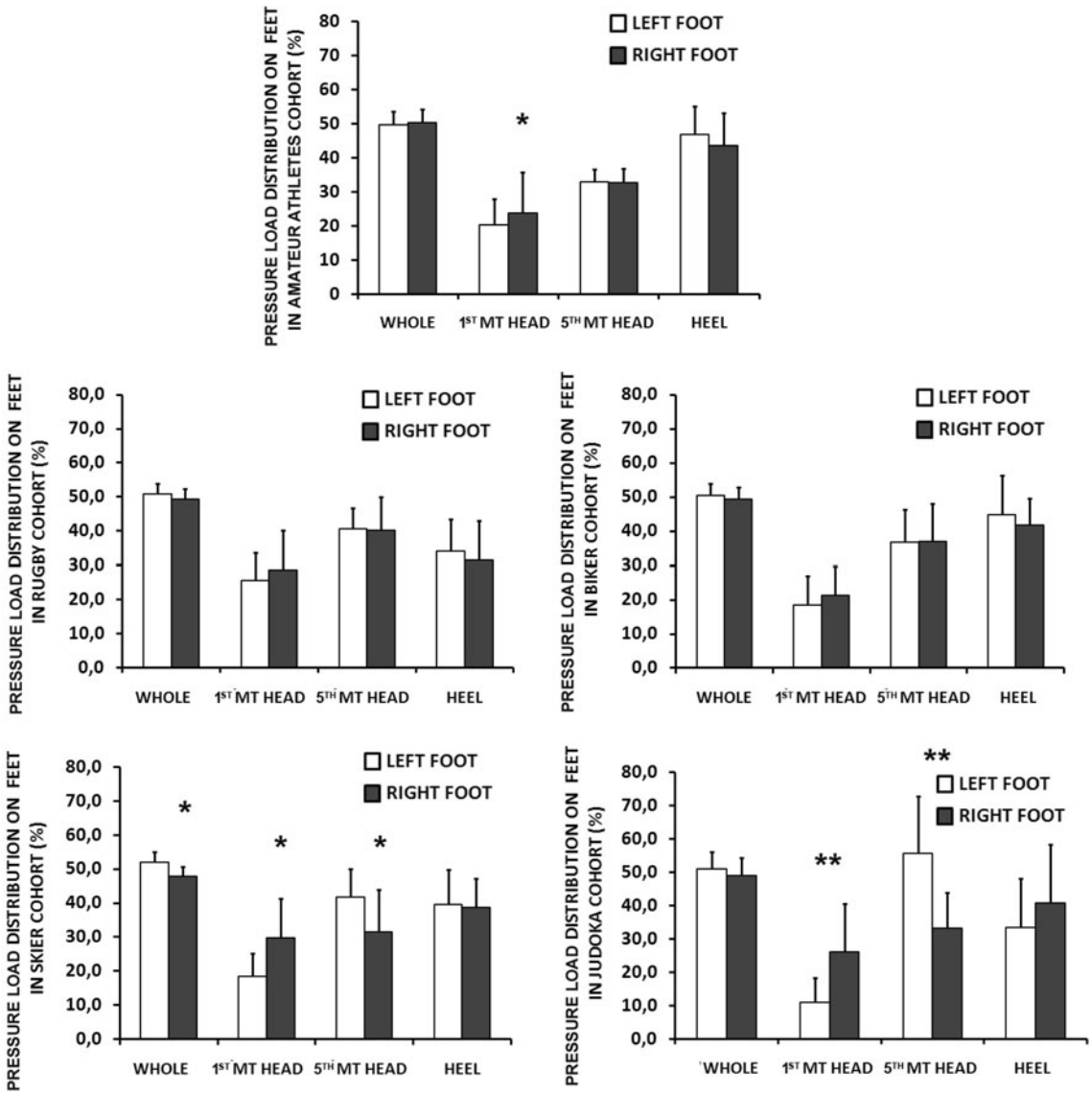

Fig. 2 Comparison of pressure load distribution between left foot and right foot in all cohorts. The cumulative weight on left foot and right foot (*whole*) and its distribution on the three points for static support were analyzed: first metatarsal head (*1st MT head*), fifth metatarsal head (*5th MT head*) and heel (*heel*). $*p < 0.05$; $**p < 0.001$

differences were observed among all the groups at the left fifth metatarsal head. The judokas' feet exhibited the highest pressure on the fifth metatarsal head, and the lowest on first metatarsal head (Fig. 1).

Figure 2 showed the load distribution between the left and right foot in each group. No significant differences were found between rugby players and bikers. On the contrary, the skiers displayed an increased load distribution on the left side, particularly on the lateral forefoot. This data correlates with the decrease of load on the left first metatarsal head. Although left/right load was well distributed in judokas, in this group the differences between left and right side both on first and fifth metatarsal heads were strongly significant.

Assessment of balance

Balance control consists of controlling the body center of mass over its limits of stability [1, 6, 15], and it can be measured using the body COP as spatial reference [4, 15]. Body COP deviation from reference was measured either on the latero-lateral (Fig. 3a) and anterior-posterior (Fig. 3b) axes.

As reported in Fig. 3a, 70 % of the skiers displaced toward the left side; a marked displacement toward the left side was evident also for judokas, whereas rugby players had a body center of pressure comparable to amateur athletes.

On the contrary, if we consider the anterior-posterior displacement (Fig. 3b), rugby players demonstrated a

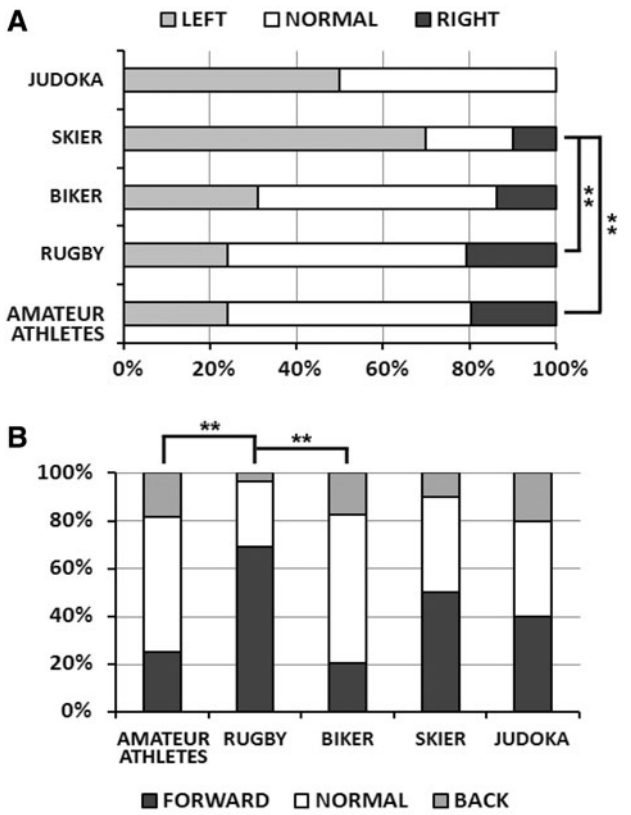

Fig. 3 Center of pressure (COP) distribution in all cohorts. The absolute distance between the real COP and its theoretical reference value was calculated both on the forward-to-back and left-to-right axes for each subject. Data was analyzed with Chi-square test. $^{**}p < 0.001$

significant forward slant showing a different postural attitude in comparison to amateur athletes as well as to the other groups of athletes (only skiers showed a tendency forward slant, in respect to amateur athletes). Bikers had the most controlled and balanced forward-back postural attitude.

Discussion

After analyzing the posture of elite athletes from different sport disciplines, we were able to identify some sports that induced unbalanced postural attitudes, while others did not. In particular, we showed evidence that the rugby players maintained an anterior displacement with a stable load reduction on the heel. However, while their center of mass is constantly forwarded, they never showed lateral displacement. Differently, 70 % of professional skiers showed a displacement of the COP on the left leg with an increased loading on the external part of the foot (fifth metatarsal bone). Of note, judokas showed a similar posture with a marked left burden and strong left COP distribution.

On the contrary, motorcyclists showed an overall balanced load distribution, even when considering left/right or anterior/posterior burden. This sport discipline, that does not require any special performance from the lower limbs, allows an intense total body training approach, not forcing a specific postural shape. It should be emphasized that the stable acquisition of an unbalanced postural attitude in rugby players, skiers, and judokas (which are not, by definition, asymmetric sport disciplines), appears as dependent on the intense training related to the top-level performances of elite athletes. It is, therefore, conceivable that the training requested to force the performance at top levels in rugby, skiing, and judo has a role in the induction of those peculiar postural shapes.

Whether the postural attitude specifically associated to a particular sport discipline is an obstacle or an advantage to obtain the best performance remains an open question at the moment. Obviously, posture must be constantly monitored during a training program of elite athletes; however, keeping in mind that recently, balance training has been adopted to prevent injuries to the ankle and knee joints during sport practices [1, 6–8, 16–18]. Rugby players, for instance, would certainly need a strengthening of extensor muscles to counteract their general postural anterior unbalancing, and to prevent muscular and joint lesions.

In summary, we do not know yet if a particular postural shape and the training aimed at correcting and improving a balanced posture would negatively affect athletic performance. Our pilot study has several limitations such as the size of our study population, the fact that the control population was not exactly parsed as the subjects of the study, and the lack of a dynamic study of the posture and balance control [19]: a more sophisticated and extensive study specifically designed for these aims measuring athletic performance in elite athletes of selected disciplines will adequately respond to this question. At present, we believe that top-level trainers should always monitor postural balance of their athletes, counteracting the establishment of sport-specific imbalances at the best of their possibilities, without affecting performance.

Conflict of interest The authors have no competing interests.

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