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Landing differences between men and women in a maximal vertical jump aptitude test

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Aim. **The aim of this study was to analyze the gender differences in the vertical ground reaction forces and the position of the center of gravity during the landing phase of a maximal vertical jump aptitude test.**

Methods**. The push-off, flight and landing phases of the jumps of 291 males (age=19.6±2.8 years) and 92 females (age=19.2±2.6 years), applicants to a Spanish faculty of sports sciences, were analyzed with a force platform.**

Results. **The greatest differences between men and women were found in the jump performance (women=25.6±3.5 cm; men=35.5±4.5 cm) and second peak vertical force value of the landing phase (women=5.89±2.06 times body weight; men=7.51 ±2.38 times body weight), the values being greater in the men's group (P<0.001). Correlation coefficients showed that the women utilized a different landing pattern than the one utilized by the men.**

Conclusion. **Contrary to the authors' expectations, women showed lower second peak vertical force values during the landing. Taking into account only a kinetic point of view, they would have a lower risk of injury during the landing movement of maximal jumps. The lower values in the peak force, the delay of the impact of the calcaneus and the longer path of the center of gravity during the landing phase found in the women's group were related to a landing technique that is different from that of men.**

KEY WORDS: Biomechanics - Sex characteristics - Exercise test.

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Jump tests are frequently used as a method for evaluating explosive force in the lower extremities of applicants to fire departments, police, and most of the faculties of Sports Sciences in Spain.[1, 2] These tests are also utilized by coaches and physical education teachers in their daily work in the field and schools. The subjects, researchers and coaches tend to focus on the push-off and the flight phases, because the purpose of the test is to reach the greatest jump height, usually neglecting the performance of a proper landing. The same situation occurs when an athlete is trying to reach maximal performance during a context, and does not pay attention to the landing movement. The landing phase of a jump has been reported to be a cause of injury in some sports,[3-9] and the test analyzed in this study has been taken as an example of a jump where the subject does not consciously perform a soft landing. Thus the authors believe that this results would be of interest in contexts where jumps are performed without paying attention to the landing phase, like sports training of competitions, games, etc.

The vertical ground reaction forces during a two-footed landing show a constant pattern with two peak vertical force values. The first (F1) appears at 10 ms after contact and is produced by the impact of the metatarsal heads. The second peak force value (F2)

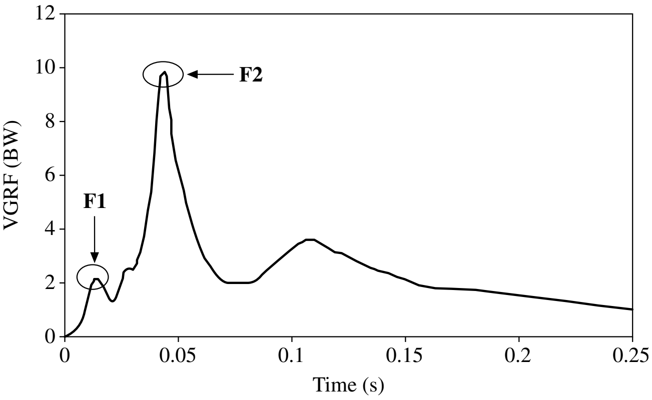

Figure 1.— Representative ground reaction force curve for a landing. F1: first peak vertical force value; F2: second peak vertical force value; VGRF: vertical ground reaction forces; BW: times body weight.

is caused by the calcaneus contact, 30 to 70 ms after the first contact, depending on the foot length and the activation of the plantarflexor muscles,[10, 11] can be as high as 10 BW (times body weight), and has been utilized to estimate the risk of injury in several sports (Figure 1).[12-14] Pflum *et al.*[15] matched F2 with the moment when the anterior cruciate ligament resists the largest strain during the landing.

Some studies have related the landing strategy, that is, how the subjects dissipate energy, with the risk of injury during this task.[10, 16-22] Therefore, it makes sense to think that a decrease in the F2 values would decrease the stress transmitted through the kinetic chain, and that it would reduce the risk of injury during the landing movement.[13, 23] This observation is important because it highlights the subjects' ability to protect themselves from the inherent risk of injury during landing, by using proper landing techniques. Some researchers, therefore, have studied how much the technique training can reduce the risk of injury in school-aged children.[24-26]

The gender differences in the risk of lower limb injury during landings have been widely studied in recent years. Based on kinematics, kinetics and muscle activation, most of these works found a greater risk of injury in women, usually associated with the anterior cruciate ligament.[8, 27-35] Hewett *et al.*[27] reported a relationship between a greater degree of knee extension and the risk of injury. In the present study, the authors estimated indirectly the degree of knee extension using the vertical position of the center of gravity assessed from kinetic data.

Hewett [36] found that F2 values during landings were 20% greater and appeared 16% before in women who injured their ACL afterward. As explained above,[8, 28, 29, 31-33, 35] women have a greater risk of injury in the anterior cruciate ligament than men. Therefore, it was hypothesized that the sample of women analyzed would show a different landing pattern and greater F2 values, compared to their male counterparts.

The purpose of this study was to analyze the gender differences in the vertical ground reaction forces and the position of the center of gravity during the landing phase of a maximal vertical jump aptitude test.

Materials and methods

Subjects

The jumps of 383 applicants to a Spanish faculty of sports sciences were recorded and analyzed. The trials were carried out in two consecutive years (2004-2005) but analyzed together, because comparing the differences between years was not within the intended scope of study. In the sample studied, there were 291 men (age=19.6±2.8 years, body mass=71.0±8.6 kg, height=174.9±5.9 cm) and 92 women (age=19.2±2.6 years, body mass=57.2±7.1 kg, height=164.3±5.9 cm).

Equipment

The jump tests were performed on a *Quattro Jump* piezoelectric force platform (Kistler, Switzerland; 0.92 m long and 0.92 m wide), connected to a computer where the force-time data were recorded at a sample rate of 500 Hz. The equipment used was similar to that utilized by Ozguven and Berme [7] and Hopper *et al.*[37] to analyze ground reaction forces during jump tests and their landing phases.

Protocols

Written informed consent was obtained from all the subjects, and the study protocol was approved by the institutional research ethics board. The participants were free to warm up at least 10 minutes before the test. Then, their height and weight were measured, and thereafter they performed the counter-movement jump test (CMJ) on the force platform. Their hands had to be placed on the hips during the whole jumping movement (push-off, flight and landing). The knee angle was not controlled, but they were instructed to keep the trunk vertical. If any of these instructions was not accomplished, the trial was invalided. All the subjects had been explained previously of the test protocols, and the researcher carried out a demonstration before the test. The subjects had to land in the same position as the one in which they took off, but they received no instruction on the landing phase. All of them had to reach the minimum jump height (29 cm in men and 21 cm in women) to pass the test; if they failed in the first trial, they performed the second jump after 1-minute rest. When two jumps were performed, only the one with the higher jump height was analyzed. It was assumed that the jumps were maximal, as the participants had no references from their jump height on the force platform before the first trial. All the subjects utilized their own indoor sports shoes.

Variables

The maximal height of the center of gravity (h) was assessed from the flight height. Peak power (PP) was assessed from the integration of the force-time record during the push-off phase,[37] and normalized by the subjects' body mass. During the landing phase were analyzed the second peak vertical force value (F2), the time elapsed from the contact to F2 (T2). F2 was normalized by the subjects' body weight. The height difference of the center of gravity between the instants of take off and landing (hl) and the vertical path of the center of gravity from the feet contact to the lowest point of the landing (Lr) were also analyzed. The values of hl and Lr were normalized to the subjects' height. The position of the center of gravity was assessed by the *Quattro Jump* software (v. 1.0.9.1), with the double integration method.[1, 38]

Statistical analysis

The data were analyzed using the software package Statistica for Windows (v. 7.0, StatSoft, USA). Descriptive statistics included mean and standard deviations, and relationships between variables were examined using Pearson correlations. A one-way analysis of variance (ANOVA) was utilized to test group differences. The P<0.05 criterion was used for establishing statistical significance.

Results

The values of the variables from the push-off phase, flight and the position of the center of gravity during the landing are shown in Table I. The greatest differences between men and women were found in the jump height and PP, the values being greater in the men's group (P<0.001) (Figure 2). The women's group showed larger Lr (P<0.05) (Figure 3).

Table II shows the results of the kinetic variables during the landing phase. The greatest differences between the groups have been found in F2, the values being higher in the men's group (P<0.001) (Figure 3). There were significant differences between the groups in T2 (P<0.05) the values being greater in the women's group.

There were significant correlations between F2 and T2 (r_{all}=-0.63, r_{women}=-0.65 and r_{men}=-0.61, Figure 4), between F2 and Lr (r_{all}=-0.56, r_{women}=-0.59 and r_{men}=-

TABLE I.—*Mean (±SD) Variables of the push-off and flight phases, and from the position of the center of gravity during the landing phase.*

	PP (W/kg)	h (cm)	Hl (%)	Lr (%)
All	47.74±7.02	33.09±5.99	3.81±1.92	10.58±2.51
Males	50.23±5.64	35.46±4.47	3.78±1.99	10.43±2.43
Females	39.85±4.78	25.61±3.53	3.88±1.69	11.06±2.72
% Differences	20.66	27.78	2.57	5.78
Sig (M/F)	***	***	ns	*

PP: peak power during the push-off phase; h: maximum height of the center of gravity during the flight phase; hl: height difference of the center of gravity between the instants of takeoff and landing; Lr: vertical path of the center of gravity from the feet contact to the lowest point of the landing; NS: not significant; F: females; M: males. *P<0.05; ***P<0.001.

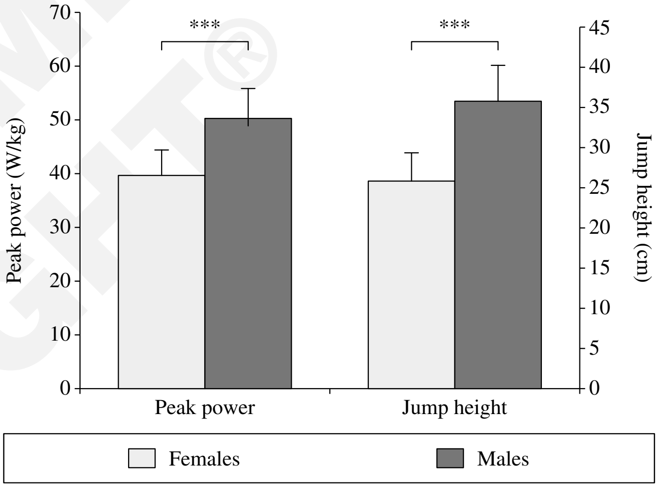

Figure 2.—Differences between males and females in the jump height and in the peak power during the push-off phase. ***P<0.001.

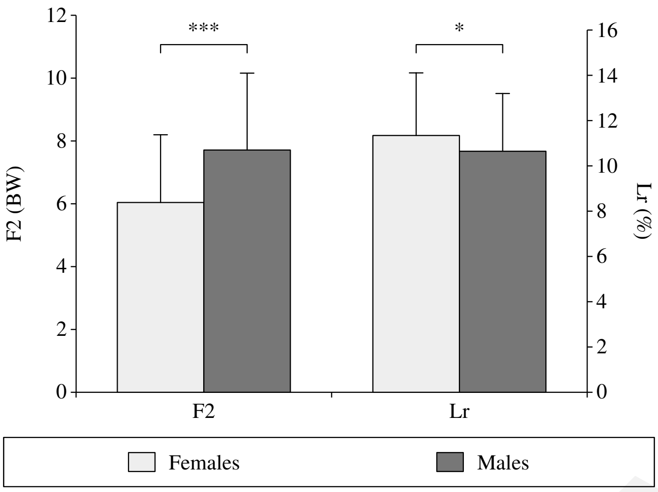

Figure 3.—Differences between males and females in the second peak vertical force value during the landing (F2) and the vertical path of the center of gravity (Lr). *P<0.05; ***P<0.001.

TABLE II.—*Mean (±SD) Variables of the push-off and flight phases, and from the position of the center of gravity during the landing phase.*

	T2 (s)	F2 (BW)
All	0.056±0.028	7.12±2.41
Males	0.054±0.030	7.51±2.38
Females	0.061±0.022	5.89±2.06
% Differences	12.59	21.54
Sig (M/F)	*	***

F2: second peak vertical force value; T2: time elapsed from the contact to F2; F: females; M: males. *P<0.05; ***P<0.001.

0.55) and between F2 and hl (r_{all}=-0.50, r_{women}=-0.60 and r_{men}=-0.50), P<0.001).

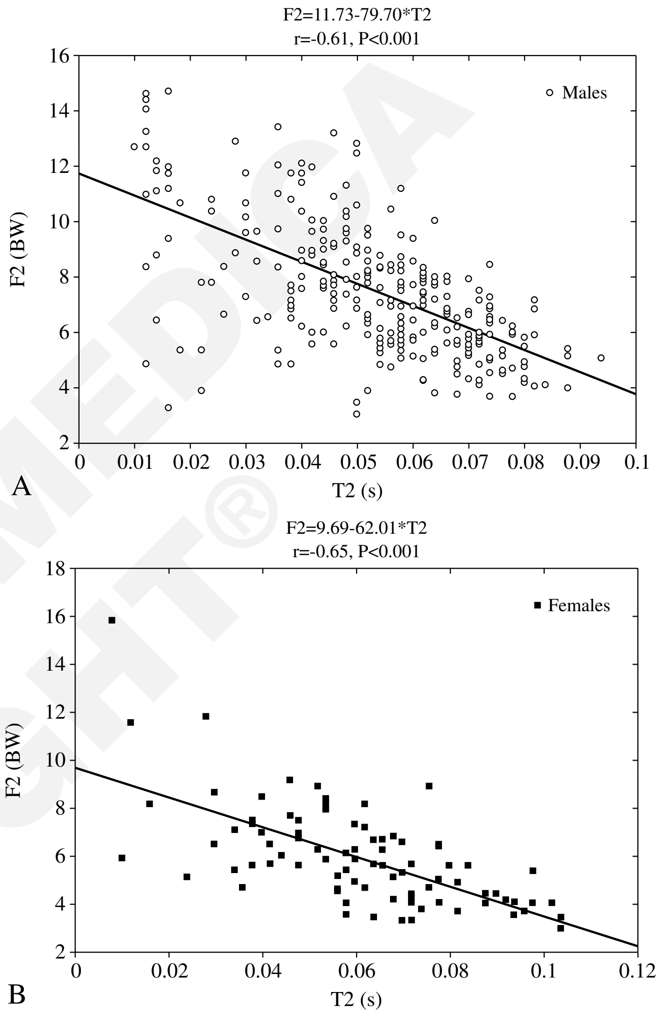

Figure 4.—Relationships between the second peak vertical force value (F2) and the time elapsed from the contact (T2) in the men's group (A) and in the women's group (B). BW: times body weight.

Discussion

The main finding of the present study was that, contrary to the authors' expectations, the women showed lower second peak vertical force values during the landing movement. This would be related to a lower risk of injury during the landings of maximal vertical jumps, at least from a kinetic point of view. The women's group delayed the calcaneus impact and showed a longer path of the center of gravity during the landing. This suggests that they utilized a different landing technique than their male counterparts.

The gender differences in the F2 values (Table II) match with those found by Hewett *et al.*,[27] who reported greater peak vertical forces in men and associated this with an increased risk of lower limb injury. But, it needs to be stressed here that, as in the study of Hewett *et al.*,[27] the men's group landed from a greater height than did the women (P<0.001) (Table I, Figure 2). The results contrast with the authors' expectations with those observed in other studies [31, 33] where the women were reported to have had an increased risk of injury; hence, it is believed that the present results could have been different if the landing height was the same in both the groups y más elevado. When the landing heights are greater, this tendency has been reported to change. In the study by Ford *et al.*[31] both groups landed from 31 cm and there were no differences in the ground reaction forces. However, Kernozek *et al.*[33] reported greater values of ground reaction forces when both groups of men and women landed from 60 cm. Unpublished data from our laboratory have found greater values in women when they landed from 75 cm (women= 8.10±1.42 BW; men=6.14±1.62 BW, $P<0.01$). There-fore, it seems that the landing height is essential when considering gender differences in landing kinetic patterns.

In another study, Hewett *et al.*[36] found a greater extension of the lower limb at the beginning of the landing movement in women, who afterwards injured their anterior cruciate ligament, because this position increased the stress on the ligament and therefore, the risk of injury. In the present study, the extension of the lower limb was estimated indirectly from the height of the center of gravity at the beginning of the landing movement. Contrary to the work by Hewett *et al.*,[36] the men's group landed with a higher position of the center of gravity, (that is, more extended) although the differences were not significant (hl_{women}=3.88±1.69%; hl_{men}=3.78±1.99%). On the other hand, the women's group showed a greater vertical range of movement of the center of gravity during the landing (Lr_{women}= 11.06±2.72%; Lr_{men}=10.43±2.43%; $P<0.05$). The last parameter, together with the lower jump heights and the greater T2, explained the smaller F2 values found in the women's group, who utilized an increased vertical range of movement and a delay of the second peak vertical force value to decrease the force values during the landing.

The F2 values of the present study ($F2_{all}$=7.12±2.41 BW; $F2_{women}$=5.89±2.06 BW; $F2_{men}$=7.51±2.38 BW) are greater than those found by other authors who analyzed landings from similar heights (h_{all}=33.1±6.0 cm; h_{women}=25.6±3.5 cm; h_{men}=35.5±4.5 cm). McNitt-Gray,[10, 16] Self and Paine [39] and Prapavessis and McNair [40] measured values from 4.16 to 4.51 BW in samples of active young men, recreational athletes and a group of men and women, respectively. Even in landings from 0.72 m, McNitt-Gray [10, 16] found lower F2 values than those measured in the present work (F2=6.38±1.70 BW). It is possible that the subjects of the studies reported above could have performed softer landings as they were instructed to land as softly as possible with free movement of the upper limbs, whereas the participants of present study were not issued any such instructions. Furthermore, the subjects had to keep their hands on hips during the whole jump, whereas the other protocols [10, 16, 39, 40] allowed the use of the upper limbs to facilitate the landing movement. Although in the landings usually performed during actual competitions or aptitude tests the athletes can move their arms, they cannot focus their attention on performing a proper landing. The authors could not ask the applicants to repeat the trial with the double purpose of reaching the greatest jump height and landing as softly as possible. Further studies should analyze whether they can achieve similar jump heights with lower F2 values, so that if they achieve then the ability of performing soft landings with maximum jump heights could be trained, although in the present study this was not measured.

The negative correlations found between F2 and T2 (r_{all}=-0.63, r_{men}=-0.61 and r_{women}=-0.65; $P<0.001$) (Figure 4) showed that as F2 was delayed, its value decreased. As explained above, another way to decrease F2 would be to increase the duration of the landing movement by a greater range of movement of the center of gravity. In fact, the authors found slight but significant correlations between F2 and Lr (r_{all}=-0.56, r_{men}=-0.55 and r_{women}=-0.59; $P<0.001$). The slight but different relationship between F2 and T2 could be another indicator of differences in the landing technique. This issue should be investigated in future studies.

The present study was carried out during actual aptitude tests that allowed to those who succeed to start a Sports Sciences degree. There were obvious time constraints, thus anthropometry and high speed kinematics could not be measured, although they would have been very useful for the analysis. On the other hand, these data have been collected during an actual test situation, where the results could show a different trend than those found in a laboratory context.

Conclusions

The peak vertical force values measured in the present work are higher than those found from greater landing heights. This is probably because in other studies the participants were asked to focus their attention on performing soft landings.

During the landing movement the women's group showed lower values in the second peak of the force-time record, which were related to the lower jump heights, the longer path of the center of gravity during the landing and the delay of the impact of the calcaneus. These are the parameters that should be taken into account if the aim is to improve the landing technique or train to decrease reaction forces during the landings from jumps.

Further studies should analyze the results of jump tests to find out whether it is possible to reduce the second peak vertical force value and yet maintain the maximum jump height. If possible, then it would also be possible to train the landing technique during actual competitions and aptitude tests.

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