Two-Leg Squat Jumps in Water: An Effective Alternative to Dry Land Jumps

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Two-Leg Squat Jumps in Water: An Effective Alternative to Dry Land Jumps

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Key words
- vertical jump
- strength training
- aquatic load plate
- unilateral

Abstract

The current study was designed to quantify and compare the kinetic parameters of two-leg squat jumps carried out on dry land, in water and in water using area devices that increase drag force. Twelve junior female handball players who had been competing at national level for the previous two years volunteered to participate in the study. Intensity of the two-leg squat jump was examined using a force plate (9253-B11, Kistler Instrument AG, Winterthur, Switzerland) in three different conditions: on dry land, in water and in water using devices. An ANOVA with repeated measurements (condition) was applied to establish differences between the three jumps. The results show that peak impact force and impact force rate for the water jumps was lower than for the dry land jumps ($p<0.05$), while peak concentric force was higher for the water jumps than the dry land jumps ($p<0.05$). In addition, no statistically significant differences were found between water jumps for these variables ($p>0.05$). These results indicate that water provides an ideal environment for carrying out jumps, as the variables associated with the exercise intensity are boosted, while those related to the impact force are reduced and this fact could be less harmful.

Introduction

Traditionally, dry land jumps have been used in sport to improve muscle force, strength, overall mobility and joint stability, as well as to prevent injuries [12,15,19]. In the therapeutic field, these exercises have been associated with different benefits, including an increase in bone mineral density [2], an improvement in motor and occupational tasks [14] and facilitation of the final stages of recovery from injury [10]. However, there are a number of risks associated with these exercises that are linked to the impact forces produced during the landing stages, and which can cause great stress to structures of the musculoskeletal system [16,23,25].

Carrying out jumps in water may be an alternative that helps to reduce articular compression forces during the landing stages by reducing impact forces [15,17,25]. This could be due to the fact that there are thrust forces in water that act on subjects to reduce their apparent weight [24]. In addition, some studies have shown that a programme of jumps in water increases power, peak concentric torque, vertical jump height and speed [15,21,23]. These improvements in performance may be due to the forces resisting forward movement (e.g. increased load) that are generated during jumps in water [5,6,23].

This leads us to believe that jumps in water may be an effective alternative to dry land jumps to produce adaptations and improvements to motor performance, with the additional advantage that they reduce the risk of injury.

In addition, certain professionals have recently used aquatic area devices that increase resistance to forward progress so as to increase intensity, thus counterbalancing the fact that apparent weight is less in water than on dry land. It has been shown that using said materials increases maximum concentric force and reduces the impact forces generated during one-leg jumps in water [25]. Despite this evidence, we believe that more research is necessary to corroborate the effectiveness of the area devices.

This study was designed to quantify and compare the kinetic parameter of two-leg squat jumps carried out on dry land, in water and in water using area devices.

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Materials and methods

Subjects

Twelve junior female handball players who had been competing at national level for the previous two years volunteered to participate in this investigation. Subject characteristics were as follows – age: 16.0±0.7 years; height: 170±10 cm; weight: 64.4±8.9 kg; and body fat percentage: 25.7±5.7 %. The subjects did not have any cardiovascular, neuromuscular, orthopaedic or psychological disorders, and were used to performing two-leg jumps during their normal sport training. The participants were notified about the potential risks involved and gave their voluntary informed consent, approved by a Research Commission belonging to our institution.

Study design

A randomised, repeated measures experimental design was used to examine the hypothesis that there were differences between two-leg jumps on dry land and two-leg jumps in water with and without devices. Subjects completed a familiarization session and a testing session 24–48 h later. The intensity of the two-leg squat jump was examined in three different conditions: on dry land, an aquatic jump and an aquatic jump using devices. The dependent variables included were peak concentric force, concentric force development rate, total time, time to peak concentric force, impact force, time to peak impact force, and impact force development rate.

Test procedures

The subjects first performed a session to familiarise themselves with the correct technique for two-leg squat jumps on dry land and in water with and without devices. After a 24–48 h break, the subjects completed the testing session in which the dependent variables were evaluated. Subjects had performed no strength training in the 48 h prior to data collection. The measurement protocols were always strictly controlled by the same evaluators with the additional help of video recording and goniometry. Subjects were always encouraged to make the maximum effort during all measured jumps. Three attempts were made at each type of jump, with the best attempt at each type of jump (e.g. peak concentric force value) chosen for analysis, also considering the landing profile of the same attempt (e.g. whether the subjects landed solidly on the plate or landed partially off the plate due to flotation). Subjects performed a general warm-up prior to both the familiarization and testing sessions, which consisted of 5 min of range of motion movements for the main joints with light jogging between exercises. Following the warm-up, subjects were allowed a practice jump prior to each different type of measured jump. All jump conditions were randomised within a jump environment to avoid fatigue effects and one minute of rest was given between trials. Due to the logistics of submerging the force plate, all dry land jumps were completed first, followed by the different types of aquatic jumps. The plate submersion and calibration required approximately 20 min, so the warm-up was repeated just prior to measured jumps. The aquatic jumps consisted of jumping with or without devices that increased drag force (i.e. the subjects took up in each hand a rectangular device through a handgrip placed in the middle of the device). The sizes of the device were: 25 cm (height)×17 cm (width)×1 cm (depth). The subjects were asked to keep their hands on their hips during the whole test (push-off, flight and landing) or, in the case of the aquatic jumps with the devices, to keep their arms straight by their sides with the devices parallel to the surface of the water. Subjects were instructed to jump as normally as possible and land as they would during training, bending the knees and avoiding violent impact with the ground. The degree of knee flexion for the starting position of the jump was set at 90° with a manual goniometer and monitored through the use of live video imaging sent to a computer.

Standing height in the water (prior to knee flexion) was at the xiphoid process (±3 cm). However, the level of immersion at the beginning of the jump was deeper since the subjects had to squat down to 90° knee flexion. Previous studies such as Miller et al. [17] and Stemm and Jacobson [23] used an immersion depth equal to the waist or less. It is known that the compressive load on the spine that is generated when running at an immersion depth equal to the waist is no different to that generated when running on dry land [8]. Since a clear mechanical difference exists between running and jumping, it is important to understand differences in impact force with different immersion depths during jumping. Although that concept was not the focus of the present investigation, a standing immersion depth of the xiphoid process (±3 cm) was chosen because previous works using walking activities at the same immersion depth found a lower impact force compared to dry land activities [3,22]. Moreover, previous studies that used general aquatic exercise programs at a similar immersion depth found positive results as regards improving physical performance [15,16,21].

Data collection and analysis procedures

Height, body mass, and body fat percentage (Tanita model BF-350) were obtained according to the protocols used in previous studies [5,7]. A portable force plate (9253-B11, Kistler Instrument AG, Winterthur, Switzerland) measuring 400 mm (width)×600 mm (length)×45 mm (depth) was used to assess ground reaction forces for all conditions tested. The force plate contained four piezoelectric sensors and each recorded the force produced in the three spatial directions. All the signals were recorded at a frequency of 200 Hz, amplified and converted A/D using a 16-bit card. We used the manufacturer's own software (BioWare® Type 2812A1-3, version 3.24) to calculate the three absolute components of the force.

Prior to calculation of the statistics parameters, each signal was corrected by the removal of the force that every subject provoked as a result of their own weight, and it was also considered that the subject's weight decreased by the flotation force. In water, the measured vertical ground reaction force while standing still in water was a result of body weight minus buoyancy, which was denominated "apparent body weight". For example, the measured vertical ground reaction force while standing still (apparent body weight) with the water at the xiphoid process was approximately 28 % (17.8±6.1 kg) of the same position on dry land (64.4±8.9 kg). Apparent body weight was further reduced when the subject reached the starting position (90° knee angle), as the body was submerged further [18]. This correction was performed with the purpose of analyzing only vertical forces of taking off phase of the jump.

Dependent variables were defined as follows: (i) Impact force as the highest ground reaction force during jump landing; (ii) Peak concentric force as highest ground reaction force before finishing the propulsive phase of the movement; (iii) Concentric rate of force development as the first peak of ground reaction force divided by the time from the initiation of the concentric phase to the first peak of ground reaction force; (iv) Total time as the

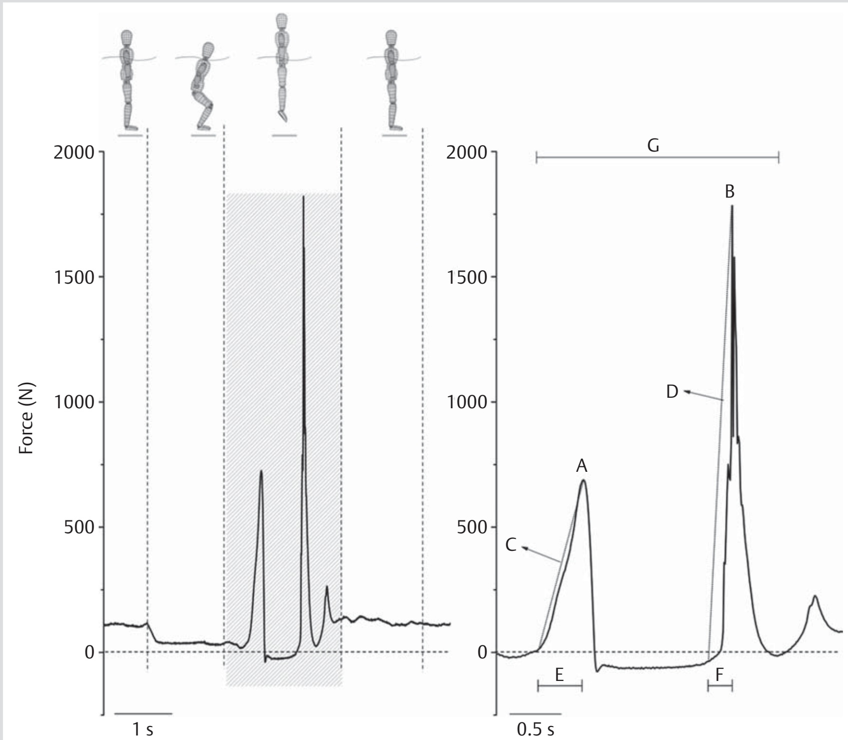

Fig. 1 Example of a standard signal and the analysis performed during the aquatic jump. On the left a typical signal of the forces generated by a subject during the aquatic jump is shown. The different phases of the jump can be observed through the dolls placed in the superior zone separated by dotted lines. The shading shows the fragment of the signal selected for the posterior analysis. On the right side an example of the statistical parameters calculated in the data reduction section is shown. As can be checked the signal force was corrected removing the force exerted by the subjects body weight on the right side signal compared to the left side signal. The statistics mean: **A**. Peak Concentric Force; **B**. Peak Impact Force; **C**. Rate of Concentric Force; **D**. Rate Impact Force; **E**. Time Concentric Force; **F**. Time Impact Force; **G**. Total Time. Although the graphical representation of the rates is not exact, it can provide a visual help to understand the calculation of these parameters. The rate impact force was calculated dividing the difference between the force at the beginning of the braking phase and the peak impact force by the time to impact force. The rate of force development was calculated dividing the peak concentric force by the time to concentric force.

time necessary to finish the propulsive phase of the movement, that is, from beginning of the propulsive phase to take-off; (v) Time to peak concentric force as the time necessary to reach peak concentric force from the beginning of the propulsive phase of the movement; (vi) Time to peak impact force as the time necessary to reach peak impact force from the beginning of the landing phase of the movement; and (vii) Rate of force development for impact force as the first peak of impact force divided by the time from the initiation of the landing phase to the first peak of impact force. ▶ **Fig. 1** shows an example of a standard signal and the analysis carried out. One previous research suggests that the mechanical power is the variable that can predict the performance [1]. We did not measure the mechanical power in the three conditions. However, some vertical ground reaction forces were considered an interesting form to quantify the intensity [13] of the exercises and other ones indicate the stress to the musculoskeletal system [11]. Test-retest reliabilities for the variables measured in the single-leg jumps (both dry-land and aquatic) were previously established with an intraclass correlation coefficient (ICC). They consistently ranged from 0.89 to 0.95.

Statistical analysis

Statistical analysis was carried out using SPSS software version 17 (SPSS Inc., Chicago, IL, USA). It was checked that all the variables complied with the assumption of normality (K-S normality test). Standard statistical methods were used to obtain the mean as a measurement of the central trend and the standard error of the mean (SEM) as a measurement of dispersion. One ANOVA with repeated measures (condition) was applied to establish differences between the three jumps. Univariate contrast was utilized to determine the main effects of the condition over the dependent variables. Greenhouse-Geisser correction was used when the assumption of sphericity (Mauchly's test) was violated, and Bonferroni correction (α/number of comparisons) was applied to avoid increasing familywise error (e.g. increasing the possibilities of having made one Type I error) because several dependent variables were included in the analysis. Helmert planned contrast was used to establish differences between the dry jumps and the two aquatic jumps and between aquatic jumps. This contrast was employed because it is more powerful than post hoc analysis [9]. The level of statistical significance prior to applying Bonferroni correction was set at $p<0.05$.

Results

The results show that the main effect on maximum concentric force ($F_{2,22}=10.52$, $p=0.001$), peak impact force ($F_{2,22}=35.98$, $p<0.001$), time to maximum concentric force ($F_{2,22}=7.55$, $p=0.003$), total time ($F_{2,22}=11.77$, $p<0.001$) and impact force development rate ($F_{1.17,12.89}=22.31$, $p<0.001$) is the medium in which the jump was performed.

Planned contrast revealed that maximum concentric force was greater when the jumps were performed in water than on dry land ($F_{1,11}=15.7$, $p=0.002$, $r=0.77$), but there were no differences between aquatic jumps. In addition, peak impact force was lower for the aquatic jumps than for dry jumps ($F_{1,11}=44.21$, $p<0.001$, $r=0.89$), and no differences were observed between aquatic jumps. Also, differences in impact force development rate between dry land and aquatic jumps were found ($F_{1,11}=24.16$, $p<0.001$, $r=0.83$), with the values for aquatic jumps being lower than the values for dry land jumps (▶ **Fig. 2**).

On the other hand, the time to maximum concentric force was higher for aquatic jumps than for dry jumps ($F_{1,11}=8.4$, $p=0.015$, $r=0.65$), and the contrast also showed that aquatic jumps with devices showed greater times to maximum concentric forces

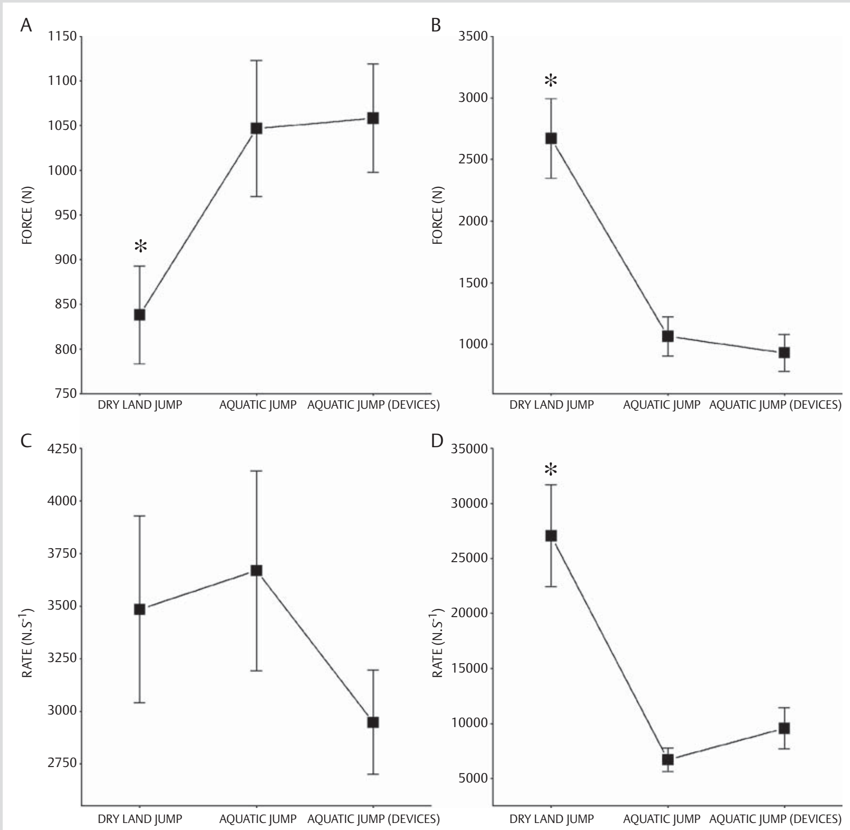

Fig. 2 Forces and rates during dry land and aquatic jumps. **A**. Peak Concentric Force; **B**. Peak Impact Force; **C**. Rate of Concentric Force; **D**. Rate Impact Force, in the three conditions. Squares represent mean (n = 12) and error bars represent standard error of the mean. * Significant differences (p < 0.05) related to both aquatic jumps.

Table 1 Differences between dry and aquatic jumps in time variables (n = 12).

	Dry Jump	Aquatic Jump	Aquatic Jump with Devices
time concentric force	0.26 (0.02) *	0.31 (0.03)	0.38 (0.02)†
time impact force	0.11 (0.01)	0.18 (0.02)	0.14 (0.03)
total time	0.36 (0.01)	0.35 (0.02)	0.45 (0.02)†

Data are expressed as mean (standard error of the mean). * Significant differences (p < 0.05) related to both aquatic jumps. † Significant differences (p < 0.05) related to aquatic jump

($F_{1,11}$ = 6.2, p = 0.03, r = 0.36) and total time ($F_{1,11}$ = 26.35, p < 0.001, r = 0.84) than aquatic jumps without devices (**Table 1**).

Discussion

The first important question associated with our study deals with the parameters used to characterise the signals acquired during the jump attempts. Despite there being a significant number of calculations to summarise the data collected during jumps, in line with other authors, we think that the impact force and impact force development rate are two parameters that indirectly indicate the stress level that the musculoskeletal system receives [11]. In addition, the intensity of the jumps can be expressed by peak concentric force and force development rate [13].

Research into jump characteristics is a well-consolidated field in scientific literature, but to date we only know of one study describing jumps in the aquatic medium. Vicente-Rodriguez et al. [27] quantified the peak force in dry squat jumps performed by female handball players and they did not show any similar data to ours within this variable. The mean value of their measure of the peak force during the dry squat jump was 519.36 N and our results indicated a value of 838.14 N when the jumps were performed on dry land. This difference can be explained by the fact that the females they studied were younger and their body mass was lower (14.2 ± 0.4 years and 53.6 ± 1.8 kg respectively) than the females in our study (16.0 ± 0.7 years and 64.4 ± 8.9 kg respectively). On the other hand, the experimental data we gathered clearly coincides with a previous study carried out by Triplett et al [25]. that measured the vertical ground reaction forces in the same three conditions but using one-leg jumps instead. Basically, our data supported the suitability of using the aquatic medium as a way of increasing the intensity of the jumps, although the differences with regard to certain parameters measured in our laboratory and those mentioned in the above study require additional explanation.

Triplett et al. [25], observed that when one-leg squat jumps were performed in water, the concentric force peaks were higher and the impact forces were lower when compared with the same jumps carried out on dry land. However, in his study the resistance materials were significantly effective, reducing impact forces by 31.6 % and increasing maximum concentric forces by 12.7 % when compared with aquatic jumps performed without using said materials.

Although our experiment also showed that both aquatic jumps generated higher concentric forces and lower impact forces, we were unable to demonstrate statistically that the use of area devices was significantly effective. The resistance offered by the material was quite possibly not high enough in our study, as the jumps were performed with both legs and the devices used were the same size as those used in the above-mentioned study. In addition, we found no significant reduction in the impact forces as a result of using the aquatic devices, despite the fact that the reduction was high (e.g. 12.7% less impact for the aquatic jumps with devices when compared with the aquatic jumps without devices). It may be that no significant differences appeared in our study because the size of the effect to be detected was very small (r = 0.28).

It should also be remembered that the maximum concentric force was maintained and even increased in the aquatic jumps, as we detected increases of 25.6% over the figure for dry land jumps for this variable when the jumps were performed in aquatic conditions. These increases may be due to the increased resistance to movement generated by the drag forces [4], which have a positive relationship with the speed of movement [5,6]. These results explain why previous studies have found a programme of jumps in water designed to improve the vertical jumps of athletes to be more effective than one carried out on dry land [15,17]. With regard to concentric force development rate, no differences were found between the conditions tested. This could be due to the fact that the time taken in water to reach maximum concentric force is prolonged, with the force development rate being reduced, despite the fact that the subjects generate higher maximum forces.

The main implications of our study centre on the use of jump exercises in water. It is known that open kinetic chain exercises in water are normally used because they can be performed easily and the drag force can be increased by using devices, all in order to increase strength and muscle mass [20,26]. The findings of the present study show that applying closed chain kinetic exercises such as jumps in water is as efficient as dry land jumps, or even more. In the sporting performance field, aquatic jumps can be used to improve overall physical capacity in periods when the workload is more important than focused training. In addition, these low impact activities can be used by obese individuals or athletes with large body masses (e.g. shot putters, heavyweight judo competitors, etc.) to improve their explosive force, as performing jumps on dry land greatly increases the risk of joint injuries for these individuals, due to the high impact forces generated when landing. They can also be very useful in slowing the reduction in neuromuscular performance that occurs with ageing [12], as the use of exercises focusing on improving explosive forces has been recommended for this population [20], and water can offer a safe environment for the musculoskeletal system.

To sum up, it seems to be clear that water is the optimum environment for performing jumps, as the variables associated with the exercise intensity are boosted, while those related to the impact force are reduced and this fact could be less harmful. However, the effectiveness of aquatic devices that increase drag forces to augment the intensity and safety of these exercises has not been proven. This information may be useful in fields associated with prevention, sporting performance, rehabilitation and health-related recreational activities.

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