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# Biomechanical analysis of the contact phase in drop jumps performed in water and on dry land

## *Análise biomecânica da fase de contato no salto em profundidade no solo e na água*

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**Abstract** – Plyometric training in the aquatic environment has been used as way of reducing loads through the action of buoyancy. However, little is known about the biomechanical characteristics of plyometric exercises in water, which can assist in the prescription of training in this environment. This study aimed to analyze the vertical component of the ground reaction force and contact duration of drop jumps (DJ) performed on land and at hip level water immersion. Participants were 22 male athletes (19.1 ± 3.7 years), who performed three maximum DJs in water and on dry land. Peak force and duration of braking and propulsion sub-phases of the DJ contact were analyzed with the use of two underwater force platforms, a 2-D waterproofed electrogoniometer, acquisition systems ADS2000-IP and TeleMyo 2400TG2, and a signal synchronizer. The effect of immersion was investigated through comparison tests for dependent samples (p <0.05). In water, the following results were observed: (a) reduction of 41.8% (p <0.001, d = 2.24) and 23.8% (p <0.001, d = 1.50) of peak forces during braking and propulsion sub-phases respectively; and (b) increase of 41.8% in the braking (p <0.001, d = 1.41) and 12.3% in the propulsion contact times (p = 0.006, d = 0.75). The aquatic environment can be an alternative when one aims to reduce the load during the DJ contact; however, the longer duration increasing of contact sub-phases in water at hip immersion may compromise the proper functioning of the stretch-shortening cycle in water.

**Key words**: Aquatic environment; Physical education and training; Plyometric exercise.

**Resumo** – *O treinamento pliométrico em ambiente aquático tem sido proposto porque reduz as cargas proporcionada pela ação do empuxo. Entretanto, pouco se sabe sobre as características biomecânicas dos exercícios pliométricos na água, as quais podem auxiliar na prescrição do treinamento neste ambiente. Este estudo teve por objetivo analisar a força vertical de reação do solo e a duração do contato do salto em profundidade (SP) realizado no solo e na água. Participaram da pesquisa 22 atletas do sexo masculino (19,1±3,7 anos), os quais executaram três SPs máximos no solo e na água (imersão do quadril). Analisou-se o pico de força e a duração das subfases de frenagem e propulsão do contato do SP com o uso de duas plataformas de força subaquáticas, um eletrogoniômetro 2-D impermeabilizado, os sistemas de aquisição ADS2000-IP e TeleMyo 2400TG2, e um sincronizador de sinais. O efeito do ambiente foi investigado através de testes de comparação para amostras dependentes (p<0,05). Na água, observou-se (a) uma redução de 41,8% (p<0,001; d=2,24) e de 23,8% (p<0,001; d=1,50) do pico de força durante as subfases de frenagem e propulsão, respectivamente; e (b) um aumento de 41,8% na duração da frenagem (p<0,001; d=1,41) e de 12,3% na duração da propulsão (p=0,006; d=0,75) do contato. O ambiente aquático pode ser uma alternativa quando se tem o objetivo de reduzir a carga durante o contato do SP; entretanto, o aumento da duração das subfases do contato pode comprometer o funcionamento adequado do ciclo alongamento-encurtamento na água.*

**Palavras-chave**: *Ambiente aquático; Educação física e treinamento; Exercício Pliométrico.*

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# INTRODUCTION

Jumps are common and fundamental movements to various sports (volleyball, basketball and athletics, among others) and are exercises often used as a form of training in various sports as well as a tool to evaluate capabilities such as force and power of the lower limbs. One of the methods used for training jumps is plyometric training, which is the use of exercises that enhance the use of muscle stretch-shortening cycle (SSC) by conducting an intense eccentric action immediately followed by a rapid concentric action[1].

Recent studies have shown the effectiveness of plyometric training for the improvement of performance variables such as agility[2], speed[3], power and height of vertical jumps[4], strength and explosive power of the lower limbs[5]. Plyometric training sessions use different types of jumps such as drop jumps, sequential jumps, unilateral jumps, jumps over obstacles, side jumps, among others. According to Stemm and Jacobson[6], the exercises used in plyometric training are of high intensity, since most of them consist of jumps and landings followed by jumps.

Due to the high intensity, some authors postulate that there is a potential risk of injury associated with this form of training[7,8] and, therefore, the performance of plyometric training in the aquatic environment[8-10] has been recently proposed, considering the reduction of impact forces due to the action of buoyancy. This reduction has been evidenced in literature during the performance of various exercises such as walking[11], running[12], stationary running[13] and jumps[7,14,15].

However, although the reduction of loads during landing of jumps is considered beneficial, when it comes to the risk of injury, water resistance can compromise the goals of plyometric training, since the duration of the contact phase is likely to be higher compared to exercises performed on dry land, and consequently the transition speed between eccentric and concentric actions will be lower. For the elastic energy stored during SSC eccentric action to be optimally used and the stretch reflex to be efficiently activated, resulting in an enhancement of subsequent concentric action; this transition should take place as soon as possible[1,16,17]. At hip water immersion, it is likely that this condition is not satisfied due to the effect of water physical properties on the temporal characteristics of movement, which in turn could lead to inefficient functioning of SSC.

Given the growing interest in the use of plyometric programs in water, it is believed that the analysis of biomechanical aspects during the execution of different plyometric exercises can provide evidence for their prescription, aiding in the understanding of the SSC stimulus in the aquatic environment. Since drop jump (DJ) is one of the exercises most widely used in plyometric training[16-18], this study aimed to analyze and compare the vertical component of the ground reaction force and contact duration of DJ performed at hip immersion in water and on dry land.

## METHODOLOGICAL PROCEDURES

### Participants

This study included 22 male track and field, volleyball and soccer athletes (19.1 ± 3.7 years; 73.6 ± 9.1 kg and 1.83 ± 0.08 m). All agreed to participate in the study by signing the Informed Consent Form and study procedures were approved by the Ethics Committee for Research Involving Human Beings of the University of State of Santa Catarina (No. 334,928 / 2013). The following inclusion criteria were used: (1) regular participation in training sessions using on land plyometric exercises as part of the training routine (at least 3 times per week and lasting at least one hour per session); (2) at least two years of experience in a sport at competition level; (3) to be able to perform the bounce drop jump technique[17]; and (4) to be adapted to the aquatic environment. Exclusion criterion is the presence of any musculoskeletal impairment reported during the first contact / interview, and / or the occurrence of injury within six months prior to data collection.

### Instruments

For the analysis of the vertical component of the ground reaction force and contact duration of DJ, two force plates were used (one for collecting data on land and another in water), which were built based on the study by Roesler and Tamagna[19] (dimensions: 500mm x 500mm x 100mm; sensitivity: 2 N; error less than 1%). Force plates were covered with non-slip material and connected to the ADS2000-IP system (AC2122, Lynx Tecnologia Eletrônica LTDA, Brasil). For determining the instant of maximum flexion of knees during the DJ contact phase, 2-D electrogoniometer (SG110, Biometrics Ltd, UK) waterproofed for use in the aquatic environment and connected to TeleMyo 2400T G2 system (Noraxon Inc ., U.S) was used. The systems were synchronized using Compact Wireless Sync (Noraxon Inc., USA).

### Procedures

As soon as the subject came to the laboratory on the day of data collection, the following anthropometric measurements were obtained: body weight, height and height of the upper edge of the iliac crest (anatomical structure of reference used to determine the level of immersion in water). To this end, digital scale (MEA-08128, Plenna, Brasil), a stadiometer (Wiso, Brasil) and an anthropometric measuring tape (CESCORF Equipamentos para Esporte LTDA) were respectively used. Then, the electrogoniometer was positioned and fixed on the knee joint as follows: subject in the standing position, one of the rods was fixed on the thigh segment in the line formed between the greater trochanter and the lateral epicondyle of the femur, and the other rod was fixed on the line formed between the lateral epicondyle of the femur and the lateral malleolus of the fibula. The fixation of rods was held with waterproof adhesive tape (Silver Tape, 3M do Brasil).

For operational purposes, all tests were first performed on dry land, and then, in water. For collections in water, the platform was positioned on the bottom of a heated swimming pool (29 ± 1° C) with an inclination that allowed individual adjustment of the hip immersion level, which corresponded to the subject's height of the upper edge of the iliac crest (1.03 ± 0.06 m). In both conditions, DJ was carried out starting from a box of 0.4 m in height, positioned close to the force platform at an adjustable distance. Participants were requested to perform the bounce drop jump technique[17] based on demonstration performed by one of the researchers and the following instructions: "Make contact with the platform the fastest as possible and jump as high as you can". Subjects performed the DJ with hands on hips (in order to eliminate the effect of upper limb movement on performance) and barefoot (to enable direct comparison between environments and eliminate the effect of different shoes).

After instructions, subjects performed warm-up exercise consisting of 10 minutes of walking on a treadmill at a comfortable speed, and then went through a period of familiarization, where they performed three submaximal DJs from height of 0.4m. Then, the phase of data collecting on dry land began, and each subject performed three maximum DJs with an interval of at least 30 seconds between attempts. The attempt in which the subject landed with both feet on the platform was considered valid, keeping hands on hips throughout the movement, and knees extended during the flight.

After data collection on dry land, participants went to the swimming pool and were submitted to a period of familiarization with the equipment, followed by warm up consisting of five minutes of various exercises (stationary running and jumps with countermovement). After warm up, subjects were instructed to repeat the jump technique performed on dry land. Again, three landings were performed from a height of 0.4 m for at least three submaximal DJs. Following familiarization, each subject performed three maximum DJs. As on dry land, subjects were encouraged to perform contact as soon as possible and jump as high as possible. The interval between executions and the criteria for the attempt validity were identical to those described for executions on dry land.

## Variables analyzed

This study analyzed the DJ contact phase, which is the interval between the first contact with the platform after the fall of 0.4 m from the box and the last contact that preceded the maximum vertical jump. This phase was divided into two sub-phases: (i) Braking: starts at first contact with the ground after the fall and ends in the event of the maximum angle of knee flexion; and (ii) propulsion: starts in the event of the maximum angle of knee flexion and ends at the time of loss of contact before the vertical jump. We analyzed if (i) the peak vertical force during braking ($PF_{braking}$) and during propulsion ($PF_{propulsion}$), both expressed in body weight units (BW) measured off the water; and (ii) the time of contact of the braking sub-phase ($T_{braking}$) and propulsion sub-phase ($T_{propulsion}$), both expressed in milliseconds.

### Data processing and statistical analysis

All data were analyzed by treatment routines developed by Scilab software version 4.1.2 (INRIA, France). For each variable, the average values of the three executions carried out by each subject in each condition were calculated. The comparison between environments was performed using the Student-t test for dependent samples (normal distribution) and the Wilcoxon test (non-normal distribution), with 5% significance level. The effect size was estimated by Cohen's d for two dependent groups using the G-Power software version 3.1.3 (Universität Kiel, Germany). All other statistical procedures were performed using SPSS 20.0 software (IBM Inc., USA).

## RESULTS

The results demonstrate that the environment was able to significantly change the force and time variables during the DJ contact phase (Table 1). The aquatic environment caused reduction of 41.8% in $PF_{braking}$ and 23.8% in $PF_{propulsion}$. For time variables, the aquatic environment caused a greater duration of braking and propulsion contact phases (increase of 41.8% for $T_{braking}$ and 12.3% for $T_{propulsion}$, respectively).

**Table 1.** Mean and standard deviation of the study variables and results for comparison between environments.

| Variables | Dry land | Water hip immersion | cl Difference (95%) | p-value | Effect treatment |
|---|---|---|---|---|---|
| $PF_{braking}$ (BW) | 5.5 (1.4) | 3.2 (1.1) | 1.8 to 2.8 | <0.001 | 2.24 |
| $PF_{propulsion}$ (BW) | 4.2 (1.0) | 3.2 (1.1) | 0.7 to 1.3 | <0.001 | 1.50 |
| $T_{braking}$ (ms) | 148.9 (36.1) | 211.1 (62.1) | -81.8 to -42.6 | <0.001 | 1.41 |
| $T_{propulsion}$ (ms) | 139.6 (33.9) | 156.8 (34.8) | -27.4 to -7.1 | 0.006 | 0.75 |

Note: CI: confidence interval; $PF_{braking}$: peak vertical force during braking sub-phase; BW: Body weight units; $PF_{propulsion}$: peak vertical force during propulsion sub-phase; $T_{braking}$: time of braking sub-phase contact; ms: milliseconds; $T_{propulsion}$: time of propulsion sub-phase contact.

## DISCUSSION

The main findings of this study indicate that during the DJ contact phase in the aquatic environment with immersion at hip level (corresponding to the height of the upper edge of the iliac crest), the maximum vertical force during braking and propulsion sub-phases is smaller and the duration of sub-phases is higher when compared to values found for executions on dry land. Additionally, it was observed that the effect of the environment is more pronounced during the braking sub-phase of contact.

The reduced load during eccentric actions is reported by Miller et al.[8] as one of the benefits of using the aquatic environment for the performance of plyometric training. However, increasing the eccentric load during the braking phase of contact is usually the goal of using DJs, seeking to stimulate the mechanisms of elastic and reflex potentiation of the muscle in activity[20]. It is during this sub-phase that the storage of elastic potential energy and the stimulation of muscle spindles occur[1,21] to enhance the subsequent concentric action. In the training practice, a way widely used to modulate the eccentric load is varying the drop height[20]. A very small height will not produce adaptations in the jumping ability, and a very great height will lead to an excessive increase in eccentric load, which can lead to inhibition of the stretch reflex as a protective strategy, reducing the effectiveness of SSC[20,22].

In this context, it is possible that the aquatic environment, by significantly reducing load during the braking phase, does not provide adequate stimulus for the effective development of SSC. However, lower drop heights and less intense loads are preferable in the initial stages of adaptation to training and increases must be gradual[16]. Additionally, the load reduction during braking sub-phase in water can be one of the reasons for lower levels of delayed onset muscle soreness[23] and / or the lower concentration of muscular stress markers[9] reported in literature for individuals who perform aquatic plyometric training compared to those who perform ground plyometric training.

Along with the reduction of eccentric loads, another aspect that encourages the use of jump training in the water is the possibility of increasing concentric overload due to water resistance during movement[7,8,14]. Although higher $PF_{propulsion}$ values were expected in water because the upward movement needs to "overcome" water resistance, the reduction found in this study (approximately 24%) can be partly explained by the buoyancy principle, which results in less apparent weight in the aquatic environment. It is important to consider that although correlations between $PF_{propulsion}$ and jump height has been shown to be strong [24] or moderate [25], larger $PF_{propulsion}$ values do not necessarily reflect higher performance in vertical jumps. Studies have shown that although $PF_{propulsion}$ values are higher in DJ than in the countermovement jump for volleyball and handball players, jump height is lower[20,26].

In addition to the peak forces in the braking and propulsion sub-phases of contact, the temporal variables also deserve attention since for the performance of a plyometric exercise, the short duration of the contact phase is decisive. Regarding the duration of the on land contact sub-phases, considerably lower $T_{braking}$ and $T_{propulsion}$ values were reported by Viitasalo, Salo and Lahtinen[27] for triple jump athletes (67 ms and 99 ms, respectively) and by Kellis, Arabatzi and Papadopoulos[28] for distance jump athletes (80 ms and 110 ms, respectively). The values found in this study for $T_{braking}$ are similar to those obtained by Bobbert et al.[20] for physically active students (140 ms), who also performed jumps barefooted.

In the aquatic environment, the $T_{braking}$ duration was approximately 42% higher compared to the ground. $T_{braking}$ is crucial for the performance on exercises using SSC, since the potentiation effect caused by prior muscle stretching on the concentric action is greater with increasing eccentric action speed and decreases the time of transition between sub-phases[20,29]. The peak eccentric action speed during DJ depends on the maximum descending speed of the individual's center of mass[16], and in water, this speed is reduced due to buoyancy and resistance, causing slower eccentric action.

Considering the differences found for braking and propulsion sub-phases of contact, it is necessary to evaluate the use of DJs in the water as a form of training, depending on the established goal. According to Flanagan and Comyns[16] and Walsh et al.[18], training using exercises in which SSC is slowly performed may not be as beneficial for athletes who primarily need fast action in sports. According to Jurado-Lavanant et al.[9], one should take into account the principle of specificity: although plyometric training in water appears to be safer than plyometric training on land, where performance depends on the ability to immediately perform a maximum vertical jump towards a target (DJ) or the repetition of high-intensity actions (sequential rebound jumps), better results are probably achieved through plyometric training on dry land. Nevertheless, it is believed that in situations where there is need for load control during landings, for example, in a period of preparation for plyometric training or in a process of returning to practice after a period of rehabilitation, the aquatic environment can be useful and motivating. Importantly, regardless of purpose, the use of DJ in water should consider aspects such as performer's level of practice and conditions available such as depth of the swimming pool.

A major limitation of this study is that the survey participants, although familiar with plyometric training on dry land and adapted to water, did not have experience in performing plyometric exercises in water, which might have influenced the performance of DJ in the aquatic environment.

## CONCLUSIONS

The forces acting on the body in the aquatic environment, namely, buoyancy and drag forces, have a significant effect on the performance of the DJ contact phase, leading to the attenuation of the vertical component of the ground reaction force and increase in the duration of braking and propulsion sub-phases. The aquatic environment can be an alternative when one aims to reduce the load during contact; however, the significant increase in the duration of its sub-phases may jeopardize the proper functioning of SSC in the water.

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