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GROUND REACTION FORCE AND PLANTAR PRESSURE OF TWO JUMPING HEAD-OUT AQUATIC EXERCISES

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The aim of this study was to compare the biomechanical load, measured by the vertical ground reaction force (GRF), plantar pressure, and contact area of two jumping head-out aquatic exercises (cross country ski and jumping jacks) performed at 1.30 m water depth. Ten healthy male volunteers, with mean (SD) age 26.5 (4.2) yr, height 175.8 (2.6) cm, weight 73.7 (8.5) kg, body mass index 22.3 (2.5) $kg{\cdot}m^{-2}$ participated in this study. Data from both GRF and plantar pressures were obtained by using an insole system. Paired-samples t-tests were conducted to compare each variable between conditions. Significant differences between exercises were found in all variables (peak force, t(9)=2.52, p = 0.033; peak pressure, t(9)=2.41, p = 0.040 and contact area, t(9)=-2.60, p = 0.029). Jumping exercises can be a suitable option when prescribing water-based exercises.

KEY WORDS: head-out aquatic exercise, ground reaction force, plantar pressure.

INTRODUCTION: Head-out aquatic exercises are used for several purposes being recommended for individuals suffering from musculoskeletal diseases, especially when having restrictions in performing weight-bearing exercise on land, for elderly people with sarcopenia and related muscle weakness which is associated to less shock absorbing ability, for athletes recovering after lesions and for overweight and obese people reducing the stress placed on the joints. Aquatic exercise prescription should take into account an appropriate exercise selection, controlling not only the physiological intensity but also the mechanical loading of head-out aquatic exercises. This might be done through biomechanical loading assessment, generally quantifying the ground reaction forces (GRF) allowing, therefore, a more precise exercise selection and making possible to adapt load according to each person condition. Biomechanical assessment of walking in water at slow and fast speeds and with different body immersion level and of head-out aquatic exercises is limited, only few studies have been done in which biomechanical parameters were measured (Harrison et al., 1992; Nakazawa et al., 1994; Barela et al., 2006, 2008; Roesler et al., 2006; Triplett et al., 2009). Previous studies shown that GRF is influenced by several different factors, namely subject body mass, loading rate, speed/cadence of movement, type of movement or jump (walking and running on the same place or progressing) and foot contact area,(Nigg, 1983; Bobbert et al., 1991; Hills et al., 2001; Rocha et al. 2006). The vertical maximal GRF is most widely used than the anteroposterior and mediolateral components for characterizing aquatic exercises biomechanical loading. Moreover, since forces and pressures are applied to specific locations on the foot surface, assessment of plantar pressure and contact area can give additional information allowing, therefore, a more accurate characterization of the aquatic exercises. Previous studies used force platforms to measure GRF, but nowadays portable systems with insoles are available, having the advantage to obtain data in a more ecological context. Therefore, the purpose of this study was to compare peak force (vertical GRF), peak pressure and the contact area of two jumping head-out aquatic exercises: cross-country ski and jumping jacks.

METHODS: Ten healthy male volunteers with a mean (SD): age 26.5 (4.2) yr, height 175.8 (2.6) cm, weight 73.7 (8.5) kg and body mass index 22.30 (2.53) kg/m^2, participated in this study after a previous selection according to the following eligibility criteria: male subjects without lower limb pathologies; height range 172-179 cm and a foot dimension matching insole size number 42. The exclusion criteria were having recent lesion or lower limb musculoskeletal disorders that might affect both the GRF and plantar pressures data. Waders were used to isolate the insole system (PEDAR-m®, novel, Münich, Germany) (Figure 1).

Figure 1: View of a participant inside the pool.

All the participants had a familiarization period, to become adapted to the head-out aquatic exercises prior to data collection. The subjects performed one trial of twenty repetitions for each exercise in the same place, at an imposed cadence of 130 beats per minute (bpm), established with a digital metronome. The sampling rate for data collection was set at a measurement frequency of 50 Hz. Body weight inside water was used for further GRF normalization by the participants' own body weight (apparent body weight). The studied variables were estimated per foot by calculating the mean over the readings of 5 steps: vertical component of ground reaction force (GRF-V) expressed in absolute value [peak force adjusted to body weight [GRF/BW (N/kg)]; plantar pressure [peak pressure (N/cm^2)] and contact area (cm^2). For better characterization of each exercise, besides total values, partial ones were estimated as following. Concerning cross country ski exercise, a sum of both crossed feet (front right foot + back left foot; front left foot + back right foot) were done and the mean of both was estimated; additionally in order to calculate the load applied to the front and back foots, we sum values of both feet and after the respective mean was calculated. In the jumping jacks exercise firstly the sum of both feet together and apart was done respectively, and afterwards the mean of the total exercise was calculated. Paired-samples t-tests were conducted to compare peak force, peak pressure and contact area variables within each exercise and between cross country ski and jumping jacks exercises. The normality assumptions were verified using the Shapiro-Wilk test. The statistical analysis was conducted considering a 5% significance level. All data were analyzed using the IBM SPSS Statistics, Version 19.0 (SPSS Inc., an IBM Company, Chicago, IL).

RESULTS: Table 1 presents the mean values ± SD of all the variables of both exercises. In cross country ski exercise no significant differences were found between front and back foot neither for peak force (front: 1.18±0.35; back: 0.90±0.16; $t(9)=2.117$, $p = 0.063$), peak pressure (front: 17.03±4.83; back: 17.89±7.63; $t(9)=-0.32$, $p = 0.756$) nor for contact area (front: 100.40±17.02; back: 87.99±12.84; $t(9)=1.76$, $p = 0.112$). Regarding the jumping jacks exercise, significant differences were observed in peak force between feet separate (1.71±0.30) and feet together (2.06±0.49); $t(9)=-5.61$, $p < 0.001$, as well as, for contact area (feet separate: 197.43±23.2; feet together: 216.68±24.66); $t(9)=-3.61$, $p = 0.006$, but not for peak pressure ($t(9)=2.17$, $p = 0.058$).
Comparison between the cross country ski (CCS) and jumping jacks (JJ) exercises revealed significant differences in peak force (CCS: 2.08±0.34; JJ: 1.89±0.39; $t(9)=2.52$, $p = 0.033$), peak pressure (CCS: 34.93±9.56; JJ: 29.64±5.21; $t(9)=2.41$, $p = 0.040$) and contact area (CCS: 188.39±20.28; JJ: 207.06±22.41; $t(9)=-2.60$, $p = 0.029$) (Table 1 and Figure 2).

Table 1
Mean ± SD values of peak force, peak pressure, and contact area of the two aquatic exercises.

	Peak Force (BW)	Peak Pressure (N/cm^2)	Contact area (cm^2)
Cross Country Ski	2.08±0.34	34.93±9.56	188.39±20.28
Crossed right foot front	2.08±0.35	33.54±8.32	194.16±25.25
Crossed left foot front	2.08±0.39	36.31±11.28	182.62±19.48
Front Feet	1.18±0.35	17.03±4.83	100.40±17.02
Back Feet	0.90±0.16	17.89±7.63	87.99±12.84
Jumping Jacks	1.89±0.39	29.64±5.21	207.06±22.41
Feet separate	1.71±0.30 **	32.41±8.59	197.43±23.21 *
Feet together	2.06±0.49 **	26.88±3.62	216.67±24.66 *

* p<0.01; ** p<0.001.

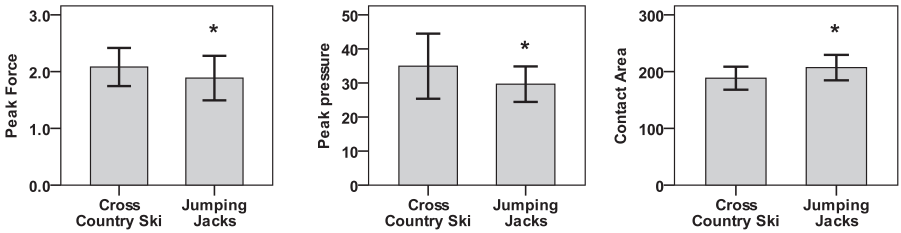

Figure 2: Comparison between cross country ski and jumping jacks exercises. * Significant difference (p<0.05) from cross country ski.

DISCUSSION: Cross country ski (CCS) and jumping jacks (JJ), are both aquatic exercises with double support in which the exchange of support is done by jumping in two different directions: anteroposterior in CCS and lateral in JJ. In the CCS exercise the double crossed supports were identical (peak force) showing a balanced distribution of the weight, but not when considering the total load on the front and back support. Although the differences observed between front feet and back feet were not significant, higher load in front feet corresponded to a larger contact area. This finding can be explained once the trunk is usually slightly tilted forwards, leading consequently to higher load on front support. Besides, it’s typical that in the front support, the whole foot tends to contact the ground, while the back foot does not completely support. In JJ exercise, peak force were higher when the feet were together, than when they were separate, but in peak pressure the opposite was observed, almost certainly due to the larger contact area in this position which were significantly different. One possible reason for the significant differences observed in peak force might be related with the technical characteristics of the exercise, specifically to the flexed knees, that may have an absorbing role when feet are apart, in relation with knee in extension in joined feet. Although both CCS and JJ exercises were classified in terms of exercise intensity (metabolic requirement) as light and moderate (Raffaelli et al., 2010), this study showed that they are different from a biomechanical point view. Higher biomechanical load of CCS compared with JJ is probably related to a larger distance of support requiring a greater muscle effort, both during landing and propulsive phases. In this study, peak force ranged from 0.90 to 2.08 BW, that are higher than the values obtained in previous studies for walking in similar immersion level performed in several variants (Nakazawa et al., 1994, Roesler et al., 2006), but less than one-leg or two-leg squat jumps in water (Tripplet et al., 2009; Colado et al., 2010). Knowledge of mechanical load imposed to skeleton and joints is an important requirement in exercise prescription, especially for therapeutic and rehabilitation

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purposes. The absence of studies characterizing biomechanical load of these aquatic exercises limited the discussion.

CONCLUSION: Aquatic exercises are used as a strategy to avoid or reduce, continuous stress placed on weight-bearing joints during exercise, due to the effect of body partial immersion, which decrease body weight. Water buoyancy diminishes joint loading of lower extremities and spine reducing the effects of gravity. Despite of the fact that body weight is reduced inside the water, these jumping exercises provide a reasonable mechanical loading which is fundamental for maintain healthy joints and bone metabolism, but on the contrary, in people with musculoskeletal diseases with articular involvement, the effectiveness of these exercise need to be proved. Generalization of these results should be done carefully due to the sample size (N=10).

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