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GROUND REACTION FORCES OF VARIATIONS OF PLYOMETRIC EXERCISES ON HARD SURFACES, PADDED SURFACES AND IN WATER

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Subjects performed drop jumps from 46 cm, a single leg jump, counter movement jump, and squat jump on a hard surface, wrestling mat and in water. Ground reaction force data obtained via a force platform were used to determine the time to takeoff, takeoff peak ground reaction force, power, jump height, and landing peak ground reaction force. A one way repeated measures ANOVA demonstrated differences between plyometic exercises assessed for all of the variables assessed ($p \leq 0.05$), with post hoc analysis demonstrating the specific differences. Results indicate that the hard surface and mat conditions were similar for almost all of the plyometric exercises assessed for most outcome variables whereas the plyometric exercises performed in water were different than those performed on the hard surface or mat in most cases.

KEYWORDS: stretch shortening cycle, intensity, stress, progression, aquatic, compliance

INTRODUCTION: Recommendations have been made to perform plyometric exercises on surfaces that are neither too hard nor soft, since these surfaces are thought to increase injury potential or prolong the amortization phase, respectively (Potach & Chu, 2004). In an attempt to evaluate the effects of surface type on plyometric training, studies have compared plyometric training in water versus a control group (Martel et al., 2005), plyometric training on land and in water (Miller et al., 2002; Robinson et al., 2004; Stemm et al., 2007), and training on grass versus sand surfaces (Impellizzeri et al., 2008). Some evidence indicates no differences in the outcome variables assessed between land and aquatic plyometrics (Robinson et al., 2004; Stemm et al., 2007). Other studies show increases in countermovement jump performance on grass compared to sand (Impellizzeri, et al., 2008), and less soreness in the aquatic conditions (Impellizzeri, et al., 2008; Robinsion et al., 2004). At this point, little information exists with respect to the acute effects of performing plyometrics on varying surfaces.

Studies have examined acute biomechanics effects of plyometric exercises (Crowther et al., 2007; Gaitsis et al., 2008), isokinetic force (Miyama & Nosaka, 2004), muscle soreness (Miyama & Nosaka, 2004), ground reaction forces (GRF) (Gaitsis et al., 2008; Miyama & Nosaka, 2004) and power and take off velocity (Gaitsis et al., 2008; Miyama & Nosaka, 2004). These studies have compared plyometrics performed on the ground versus a mini-trampoline (Crowther et al., 2007) and on hard versus sand surfaces (Gaitsis et al., 2008; Miyama & Nosaka, 2004). Research indicates that force, power, and take off velocity are higher on rigid compared to compliant surfaces during the take off phase of the plyometric exercise (Gaitsis et al., 2008). Ground reaction forces have been shown to be higher on compliant surfaces during the landing phase of some plyometric exercises, potentially due to stiffer landings as a result of lower levels of lower body joint flexion on compliant surfaces such as sand (Crowther et al., 2007). Thus, compliant surfaces may not necessarily reduce plyometric exercise intensity.

Studies assessing plyometric exercises on a variety of landing surfaces have compared a limited number of exercises including the depth jump (Crowther et al., 2007; Miyama & Nosaka, 2004), countermovement jump (Crowther et al., 2007), and squat jumps (Gaitsis et al., 2008). Typically these only compared two exercises and two landing surface variations (Crowther et al., 2007; Gaitsis et al., 2008; Miyama & Nosaka, 2004) and did not examine the takeoff phase of the exercises. Other research compared the intensity of a variety of plyometric exercises, but did not investigate the effect of different types of landing surfaces (Jensen and Ebben, 2007). Therefore, the purpose of the present study was to evaluate the kinetic characteristics of a variety of plyometrics performed on a hard surface, wrestling mat, and in water.

METHODS: Fifteen men and women (mean ± SD; age = 21.2 ± 2.2 years, height = 170.3 ± 6.5 cm; body mass = 68.81 ± 12.15 kg) who were familiar with and used the studied exercises served as subjects in this study. Subjects provided informed consent prior to participating in the study, which was approved by the institutional review board.

Prior to the test subjects warmed up with at least 3 minutes of low intensity work on a cycle ergometer and stretched for approximately 12 seconds using one exercise for each major muscle group. Subjects then rested at least 5 minutes rest prior to beginning the test plyometric exercises. The test plyometric exercises included a drop jump (DJ) from 46 cm, single leg jump using the right leg (SLJ), counter movement jump (CMJ), and a squat jump (SJ), each performed in a randomly assigned order. A one minute rest interval was maintained between test plyometrics.

The plyometric exercises were performed on a hard surface, mat, and in water. The hard surface condition included performing the plyometric exercises on a 2cm thick aluminum plate (76 X 102 cm) bolted directly to a force platform (OR6-5-2000, AMTI, Watertown, MA, USA). Attachment of the plate resulted in a natural frequency of not less than 142 Hz, within limits recommended for this system. For the mat condition, a section of 5 cm thick closed cell wrestling mat was attached to the surface of the force platform. The water condition included performing the plyometric exercises on a force platform (OR6-WP-2000, AMTI, Watertown, MA, USA) which was placed on the pool bottom at a depth of 140 cm.

Ground Reaction Force data were collected at 1000 Hz, real time displayed and saved with the use of computer software (NetForce 2.0, AMTI, Watertown, MA, USA) for later analysis. Takeoff peak GRF, time to takeoff, power, jump height, and landing peak GRF were calculated from methods previously used (Bauer et al., 2001; Jensen & Ebben, 2007).

Data were analyzed using a repeated measures ANOVA to test main effects for takeoff peak GRF, time to takeoff, power, jump height, and landing peak GRF. Bonferroni adjusted post hoc analyses were used to assess the specific differences between the plyometric exercises. The *a priori* alpha level was set at $P \leq 0.05$. Statistical power (d) and effect size (η_p^2) were determined and all data expressed as means ± SD.

RESULTS: Significant main effects representing differences between plyometric conditions were found for the CMJ for takeoff peak GRF ($P = 0.034$, $\eta_p^2 = 0.23$, $d = 0.65$), time to takeoff ($P \leq 0.001$, $\eta_p^2 = 0.41$, $d = 0.96$) power ($P \leq 0.001$, $\eta_p^2 = 0.72$, $d = 1.00$), jump height ($P \leq 0.001$, $\eta_p^2 = 0.72$, $d = 1.00$), and landing peak GRF ($P \leq 0.001$, $\eta_p^2 = 0.66$, $d = 1.00$).

Significant main effects representing differences between plyometric conditions were found for the SLJ for takeoff peak GRF ($P=0.025$, $\eta_p^2 = 0.76$, $d = 1.00$), power ($P \leq 0.001$, $\eta_p^2 = 0.97$, $d = 1.00$), jump height ($P \leq 0.001$, $\eta_p^2 = 0.97$, $d = 1.00$), and landing peak GRF ($P \leq 0.001$, $\eta_p^2 = 0.43$, $d = 0.98$), but not for time to takeoff ($P = 0.12$).

Significant main effects representing differences between plyometric conditions were found for the SJ for takeoff peak GRF ($P \leq 0.025$, $\eta_p^2 = 0.25$, $d = 0.70$), time to takeoff ($P \leq 0.001$, $\eta_p^2 = 0.56$, $d = 0.99$), power ($P \leq 0.001$, $\eta_p^2 = 0.86$, $d = 1.00$), jump height ($P \leq 0.001$, $\eta_p^2 = 0.86$, $d = 1.00$), and landing peak GRF ($P \leq 0.001$, $\eta_p^2 = 0.57$, $d = 0.99$).

Significant main effects representing differences between plyometric conditions were found for the DJ for takeoff peak GRF ($P = 0.001$, $\eta_p^2 = 0.54$, $d = 0.99$), power ($P \leq 0.001$, $\eta_p^2 =$

0.88, d = 1.00), jump height ($P \leq 0.001$, $\eta_p^2 = 0.88$, d = 1.00), and landing peak ground reaction force ($P \leq 0.001$, $\eta_p^2 = 0.71$, d = 1.00), but not for time to takeoff (P = 0.93).

Results of the post hoc analysis demonstrating specific differences between plyometric conditions are shown in Tables1-5.

Table 1. Time to takeoff in seconds (Mean ± SD) for each plyometric exercise

	CMJ*	SLJ	SJ**	DJ
Land	0.66 ± 0.10	0.75 ± 0.26	0.48 ± 0.12	0.29 ± 0.09
Mat	0.60 ± 0.17	0.70 ± 0.19	0.48 ± 0.07	0.29 ± 0.09
Water	0.87 ± 0.31	0.86 ± 0.25	0.33 ± 0.04	0.29 ± 0.10

CMJ = countermovement jump, SLJ = single leg jump, SJ = squat jump, DJ = depth jump
*Significant difference between the Land and Water and Mat and Water conditions ($P \leq 0.05$)
** Significant difference between the Land, Mat and Water ($P \leq 0.05$)

Table 2. Peak ground reaction force, minus body mass, in Newtons (mean ± SD) during the takeoff phase of each plyometric exercise

	CMJ*	SLJ**	SJ*	DJ**
Land	921.83 ± 244.38	607.42 ± 230.04	807.51 ± 172.21	1917.81 ± 750.51
Mat	938.31 ± 314.61	612.99 ± 191.44	784.75 ± 205.87	1880.42 ± 615.05
Water	782.35 ± 353.72	264.73 ± 176.47	701.99 ± 245.87	1333.97 ± 357.61

CMJ = countermovement jump, SLJ = single leg jump, SJ = squat jump, DJ = depth jump
*Significant difference between the Land and Water and Mat and Water conditions ($P \leq 0.05$)
** Significant difference between the Land and Water and Mat and Water conditions ($P \leq 0.001$)

Table 3. Power in watts (mean ± SD) for each plyometric exercise

	CMJ*	SLJ*	SJ*	DJ*
Land	30869.16 ± 5837.22	29434.84 ± 5440.38	29674.31 ± 5034.89	30261.4779 ± 5459.03
Mat	30745.62 ± 5467.47	29489.14 ± 5433.48	29666.22 ± 5054.60	30282.93 ± 5436.72
Water	32683.95 ± 5159.68	32187.00 ± 5380.80	31811.22 ± 5083.95	32657.94 ± 5021.38

CMJ = countermovement jump, SLJ = single leg jump, SJ = squat jump, DJ = depth jump
*Significant difference between Land and Water, and Mat and Water conditions ($P \leq 0.001$)

Table 4. Jump height in meters (mean ± SD) for each plyometric exercise.

	CMJ*	SLJ**	SJ*	DJ*
Land	0.35 ± 0.08	0.15 ± 0.05	0.31 ± 0.08	0.29 ± 0.09
Mat	0.33 ± 0.10	0.16 ± 0.06	0.31 ± 0.08	0.29 ± 0.09
Water	0.65 ± 0.17	0.60 ± 0.07	0.66 ± 0.13	0.68 ± 0.18

CMJ = countermovement jump, SLJ = single leg jump, SJ = squat jump, DJ = depth jump
* Significant difference between the Land and Water, and Mat and Water conditions ($P \leq 0.001$)
** Significant difference between the Land and Mat ($P \leq 0.05$) and Land and Water and Mat and Water conditions ($P \leq 0.001$)

Table 5. Landing peak ground reaction force in Newtons (mean ± SD) for each plyometric exercise

	CMJ*	SLJ*	SJ*	DJ**
Land	2614.07 ± 1181.04	1457.82 ± 631.34	2413.16 ± 1681.38	3266.61 ± 1059.36
Mat	3088.75 ± 1492.73	1534.54 ± 593.67	2566.00 ± 1277.61	2796.38 ± 710.97
Water	782.35 ± 353.72	717.62 ± 887.44	789.97 ± 968.87	1546.12 ± 555.71

CMJ = countermovement jump, SLJ = single leg jump, SJ = squat jump, DJ = depth jump
*Significant difference between the Land and Water and Mat and Water conditions ($P \leq 0.001$)
** Significant difference between the Land and Mat ($P \leq 0.01$) and Land and Water and Mat and Water conditions ($P \leq 0.001$)

DISCUSSION: This is the first study to compare the kinetic properties of variety of plyometrics performed on a hard surface, mat, and in water. Results demonstrate that the take off characteristics including time to takeoff do not differ between the hard surface and mat conditions. This finding indicates that this type of padded surface does not appear to prolong the stretch shortening cycle. This finding is consistent with work that demonstrated no difference in the total time to execute the countermovement jump or depth jump when performed on the mini-trampoline or ground (Crowther et al., 2007). Time to take off in the water was longer than the other plyometric conditions in the present study, potentially due to lower landing GRF for depth jumps and a longer eccentric phase for the other plyometric exercises, which may not optimally stimulate the stretch shortening cycle or produce the minimal essential eccentric strain (Ebben et al., 1999). Takeoff GRF have previously been demonstrated to be higher on rigid compared to compliant surfaces (Gaitsis et al., 2008) though no differences were found in the present study between hard surface and mat for any of the exercises assessed. However, in the present study, takeoff peak GRF were lower for plyometric exercises performed in water.

Jump heights and power values were higher in the aquatic compared to the hard surface and mat conditions. Anecdotal observations suggest that jump heights are elevated in water, due to its buoyancy. Additionally, the jump heights and power values are based on calculations using flight time equations which may be falsely elevated due to the buoyancy of the water during the landing phases of the plyometrics. Gaitsis et al. (2008) found that power values were higher on a rigid surface compared to sand, whereas no difference was found between hard surfaces and mats in the present study. Landing peak GRFs were lower for the plyometric exercise performed in water. This finding suggests that aquatic plyometrics are less intense which may lead to less chronic muscle soreness, consistent with previous reports (Miller et al., 2002; Robinson et al., 2004).

CONCLUSION: These data indicate that plyometrics performed on a hard surface and a mat demonstrate similar take off and landing kinetics. Compared to plyometrics performed on hard surfaces and mats, plyometrics performed in water produce lower take off and landing ground reaction forces, slower times to take off, but produce elevated power and jump heights which may be falsely inflated due to flight time based equations.

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