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CONTACT TIME, JUMP HEIGHT, AND REACTIVE STRENGTH INDEX DURING DROP JUMPS IN WATER, ON PADDED AND NONPADDED CONDITIONS

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Twelve athletes, who routinely used plyometric exercises, performed drop jumps from 46 cm in water, on padded (5 cm thick wrestling mat), and unpadded conditions. GRF obtained via force platform and video analysis of markers placed along the leg were used to compare contact time (CT), flight time (FT), jump height calculated from flight time (JH_{FT}) and video data (JH_{VIDEO}), and reactive strength index (RSI) from both calculation techniques (RSI_{FT} and RSI_{VIDEO}). One-way Repeated Measures ANOVA indicated significant difference in CT but not FT. Two-way Repeated Measures ANOVA indicated differences in calculation technique for JH and RSI. Results indicate faults in current technique used to sample CT and JH when comparing plyometrics in and out of water.

KEYWORDS: Landing Surfaces, Stretch Shortening Cycle, Flight Time.

INTRODUCTION: Plyometric exercises are widely used to augment explosiveness of athletic movements via the stretch shortening cycle (Chimera et al, 2004). Studies by Potach et al. (2004) suggest that these exercises may increase the possibility of joint injury and therefore drop jumps above 46 cm are not recommended for individuals weighing more than 100 kg and those under 14 or over 60 years of age. To decrease the possibilities of high forces on the joints, some researchers have suggested performing plyometric exercises on padded surfaces or in water (Martel et al., 2005; Miller et al., 2002; Miller et al., 2007).
Jumping performance during a drop jump has been assessed using a variety of methods including time in contact with the landing surface after the drop from a height (CT), jump height (JH), and reactive strength index (RSI (= JH/CT)) (Ebben et al., 2008; Flanagan et al., 2008). The common technique of calculating JH from flight time may not suffice in an aquatic environment, as water may increase flight time and jump height due to upward pressure from buoyancy and drag from water resistance throughout the movement (Giancoli, 2009). Furthermore, the effects of padded surfaces on plyometric CT and RSI are unknown.
As such, the method of calculation may produce different results in aquatic conditions and on padded surfaces for jump height, and therefore RSI. However, plyometric exercises performed on padded versus unpadded conditions and in water have not been extensively studied. Therefore the purpose of the current study was to examine the effect of condition on calculation technique through CT, JH, and RSI while performing drop jump exercises on padded surfaces, unpadded surfaces, and in water.

METHODS: Twelve track and field athletes (eight women and four men; mean ± SD; age = 22.3 ± 3.9 years; body mass = 69.5 ± 14.3 kg; height = 172.3 ± 6.5 cm) lacking musculoskeletal disabilities or injuries, volunteered to serve as subjects for the study. All subjects used the studied exercises in their regular resistance-training regimen, though not on padded surfaces or in water. Subjects completed a Physical Activity Readiness-Questionnaire and signed an informed consent form prior to participating in the study. Approval for the use of human subjects was obtained from the Institutional Review Board prior to commencing the study. Subjects had performed no strength training in the 48 hours prior to data collection.
Warm-up prior to the plyometric exercises consisted of a minimum of 3 minutes of low intensity exercise on a cycle ergometer, followed by static stretching including at least one

movement for each major muscle group, with stretches held from 12-15 seconds. The subjects were then allowed at least 5 minutes rest prior to beginning the plyometric exercises. The order of landing conditions for the 46 cm drop jumps was randomly assigned. A one minute rest interval was maintained between each jump.

The drop jumps were performed by stepping forward off a 46cm tall raised platform onto a force platform (OR6-5-2000, AMTI, Watertown, MA, USA), landing in a bilateral stance followed immediately by a countermovement jump. Subjects were encouraged to jump with maximal effort. For padded and unpadded conditions, subjects performed the drop jumps on a 2cm thick aluminum plate (76 X 102 cm) bolted directly to the platform to increase the landing surface area to decrease chances of injury. Attachment of the aluminum plate resulted in a natural frequency of no less than 142Hz; within limits recommended for this data collection (AMTI). For the padded condition, a section of a 5 cm thick closed cell wrestling mat was attached to the face of the force platform with elastic bands. For drop jumps performed in water, a force platform (OR6-WP-2000, AMTI, Watertown, MA, USA) was placed on the bottom of a pool with a water depth of 140cm.

Ground reaction force data were sampled at 1000Hz and saved through computer software (NetForce 2.0, AMTI, Watertown, MA, USA) for later analysis. Contact time (CT) was defined as the time between first foot contact with the force platform (onset defined as a value greater than 10 N) and when the subject's feet left the platform (defined as a value less than 10 N).

Video of the exercises was obtained from a 640x480 pixel camera (Optura 20, Canon USA Inc, Lake Success, NY) at 60Hz from the right sagittal view using 1cm inked markers placed at two points along the femur, two points along the fibula, and points on the lateral malleolus and the fifth metatarsal. Markers were digitized by one investigator in order to reduce error (Winter, 1990) using video analysis software (Motus 8.5, Peak Performance Technologies, Englewood, CO, USA) and acceleration of the body position center of mass was determined after data were smoothed using a fourth order Butterworth filter (Winter, 1990).

Jump height was determined using the force platform (JH_{FT}) and video analysis (JH_{VIDEO}). For video analysis, JH_{VIDEO} was defined as the distance the marker on the malleolus moved from lowest point when in contact with the force platform to the highest point during the jump. Flight time during the drop jumps was defined as the time between when the subject's feet left the force platform and subsequently contacted it again. FT was used to calculate JH_{FT} using the formula $(9.81 * FT^2)/8$ (Flanagan et al., 2008; Giancoli, 2009). The RSI was calculated as JH divided by CT using jump height from video (RSI_{VIDEO}) data and calculated from flight time (RSI_{FT}).

Statistical comparisons were made for CT and FT using SPSS (v.18) via One-Way Repeated Measures ANOVA. JH and RSI were compared relative to calculation technique using a Two-Way Repeated Measures ANOVA. Significance was set at $\alpha = 0.05$ and follow-up pair-wise comparisons were performed with Bonferroni's correction when significant differences were found. Effect size was calculated and based on a scaled classification (Hopkins, 2002) of f values converted to η_p^2, where $f = \eta_p^2/(1- \eta_p^2)^{0.5}$. Scale of η_p^2 was classified as <0.04 = trivial, 0.041-0.249 = small, 0.25-0.549 = medium, 0.55-0.799 = large, and >0.8 = very large.

RESULTS/DISCUSSION: As seen in Table 1, results indicated a significant difference (*p<0.05*) in CT between water and other conditions. This finding may be attributed to water resistance slowing the countermovement (Giancoli, 2009). As such, direct comparison of CT data may not be appropriate for gauging plyometric performance between water and land conditions. Padded conditions did not create a significant (*p>0.05)* different in CT compared to unpadded conditions, however. Thus, the potential shock absorption properties of a padded condition do not significantly impair CT.

FT did not differ significantly (*p>0.05)* between any condition, but it did increase from the unpadded condition to padded and water, as seen in Table 1. This slight, non-significant increase in FT for the water condition may also be attributed to water resistance and buoyancy slowing the fall of the subject to the platform (Ebben et al., 2010).

Table 1
CT and FT (Mean±SD) relative to condition and effect size.

	Unpadded	Padded	Water	Effect Size
CT (s)	0.293±0.080	0.280±0.049	0.497±0.085*	0.893
FT (s)	0.505±0.061	0.514±0.059	0.562±0.088	0.265

*Significant difference from Unpadded and Padded Conditions ($p < 0.05$)

Jump height data, significantly differed ($p < 0.05$) for all conditions regardless of calculation technique. For both JH_{FT} and JH_{VIDEO}, JH was higher in padded conditions than unpadded and highest in water conditions. Jump height may be higher in the water condition due to buoyancy (Giancoli, 2009). As such, JH may not be a valid calculation technique when comparing performance between conditions due to this buoyancy effect. There was no interaction between conditions and calculation technique for JH ($p>0.05$).
Two-Way Repeated Measures ANOVA indicate the JH_{VIDEO} technique compared to the JH_{FT} technique produced small but significant differences ($p < 0.05$), especially in water conditions. This may be due to the buoyancy effect of the water (Ebben et al., 2010; Giancoli, 2009). The three conditions were, however, all significantly different ($p < 0.05$). The calculated JH from may be inaccurate, however, as JH_{VIDEO} was determined from the lateral malleolus; the level of plantar flexion may increase the height of the subject at the takeoff point and change the estimated start of flight time.
JH_{FT} calculations may also result in erroneous data in water plyometrics due to the increase in CT and FT offsetting the calculations due to buoyancy. These flaws in calculations may explain the differences seen between JH_{VIDEO} and JH_{FT} in Figure 1 (A). Effectively, FT cannot be used to accurately calculate JH in water conditions.

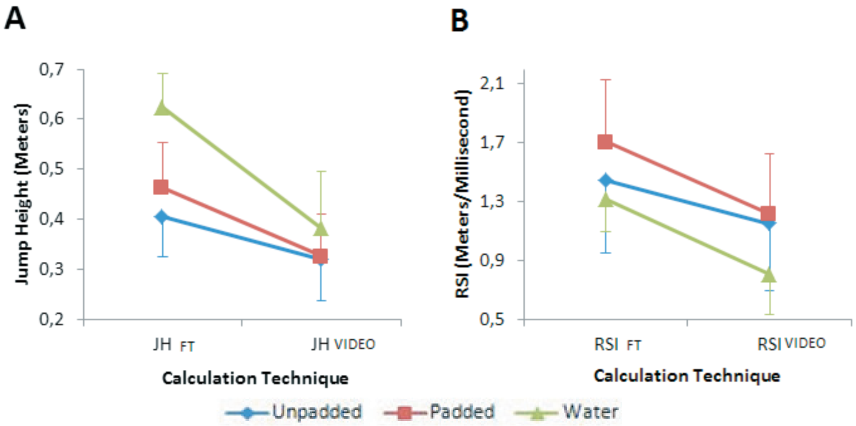

Figure 1: Comparison of technique used to calculate (a) JH and (b) RSI (Mean±SD).

Two-Way Repeated Measures ANOVA indicated, as seen in Figure 1 (B), that RSI_{VIDEO} was different in the water condition compared to the padded and unpadded conditions but that the padded condition results vary from the others more significantly ($p < 0.05$) with the RSI_{FT} technique. This illustrates an interaction between condition and calculation technique, as seen by the changed relationship between calculation techniques of the unpadded condition. These changes are a result of changes in JH and CT relative to padded, unpadded, and water conditions and technique used to calculate JH.
In order to investigate the interaction, further One-Way Repeated Measures ANOVA were performed and indicated that the RSI_{FT} technique significantly differs ($p < 0.05$) only between padded and water conditions. RSI_{VIDEO} technique displayed significant differences ($p < 0.05$) between unpadded and padded conditions, and between padded and water conditions.

Differences between the techniques used are likely a result of the changes in technique when processing JH, because the same jumps were used for comparison.
Problems may arise, however, from calculating CT and JH from video data due to the decrease in sampling rate from force platforms to cameras (in the case of the equipment used for the current study, from 1000Hz to 60Hz). This decrease will result in the loss of data and therefore accuracy, but may be alleviated by using cameras with higher sampling rates.

CONCLUSION: The differences in technique used to calculate JH, and by extension, RSI, produce large enough of effects that care must be taken when comparing plyometrics performance in and out of water. The changes in FT due to buoyancy and water drag impact traditional calculations of JH when only using FT data. As such, when comparing performance in and out of water, JH derived from video analysis can possibly result in more accurate outcomes, as long as level of plantar flexion is taken into effect and measures are taken to increase sampling rate. While differences in technique have an effect in comparing padded and unpadded conditions, that effect is much smaller. Overall, plyometrics in water increases the complexity of data analysis by possibly creating flaws in results derived from FT calculations. Video analysis may alleviate these issues, but introduce complexities that must also be taken into account.

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