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Effect of Increasing External Loads on Countermovement Jump Landing Kinetics between NCAA DI Women's Soccer and Gymnastics on Land vs in Water

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ABSTRACT

The purpose of this study was to compare the effect of differing loads on landing kinetics on land, and in aquatic conditions. Twenty four NCAA DI athletes volunteered for this study twelve female soccer players and twelve female gymnasts. Participants performed three jumps with four differing external loads in both land and aquatic environments. External loads were body weight (BW), BW*1.1, BW*1.2, BW*1.3 and applied via a weighted vest. All external loads for both conditions were added based upon participants BW on land. Kinetic measures were peak force, rate of force development, and impulse of the landing phase of the plyometric countermovement jump. Data was collected via waterproof force-plate. Results were analyzed using a three-way repeated measures 2x2x4 ANOVA. There was no significant difference in any result based on sport. Aquatic environments reduced peak impact by 50.7%, rate of force development by 53.5%, and impulse by 38.6%. Increasing external load did not produce significant differences for impact peak force or rate of force development, but did produce significantly higher impact impulse for land based jumps ($p=0.000$). In an aquatic environment increasing load produced significant differences in all three kinetic values. The results for environment agree with previous studies. The results for loaded aquatic countermovement jumps in this study show increased landing kinetics over unloaded aquatic jumps, and decreased landing kinetics over unloaded land jumps. Adding external load in aquatic environments may utilized to increase landing kinetics, while remaining under kinetic values of land based plyometrics.

Introduction

Plyometrics are exercises that allow neuromuscular groups to reach maximum contractile strength as quick as possible through what is known as the stretch shortening cycle (SSC) (Chu, 1998). The SSC is activated by providing a short eccentric contraction of targeted neruomuscular groups prior to a maximum concentric contraction. Plyometric exercises have traditionally been utilized by athletes looking to increase production of strength in short periods of time, this is known as power (Arazi & Asadi, 2011; Behrens et al., 2016; Fernandez-Fernandez, Sáez De Villarreal, Sanz-Rivas, & Moya, 2016; Hall, Bishop, & Gee, 2016; Hunnicut, Elder, Dawes, & Elder, 2016; Michailidis, 2015; Miller, Berry, Bullard, & Gilders, 2002; Mirela, Raducu, Antoanela, Carmen, & Laura, 2014; Singh, & Winder Singh, 2013). While increasing power, plyometrics have also been linked to long term prophylaxis by increasing static and dynamic balance, agility, opposing muscle group strength ratio, and bone mineral density (Arazi, & Asadi, 2011; Behrens et al., 2016; Markovic, & Mikulic, 2010; Ay, & Yurtkuran, 2005). Because of this, recent studies have suggested implementing plyometric exercises in rehabilitation (Chmielewski, Myer, Kauffman, & Tillman, 2006; Chu, 1998), injury prevention programs for the elderly (Searle, 2015; de Vos et al., 2005; Piirainen, Cronin, Avela, & Linnamo, 2014), as well as neuromuscular training for certain medical disabilities (Gehlsen, Grigsby, & Winant, 1984; Johnson, Salzberg, MacWilliams, Shuckra, & D'Astous, 2014).

The countermovement jump has been used as a reliable test for lower body power, and is a common exercises used by most lower extremity plyometric programs. The countermovement jump is performed by allowing gravity to place a small, quick, eccentric load on the quadriceps, just prior to maximal concentric contraction used to propel the individual into the air (Figure 1). While producing desired outcomes listed above, countermovement jumps are associated with undesirable effects of higher initial injury risk, and muscular soreness (Atanasković, Georgiev, & Mutavdzić, 2015; Hreljac, Marshall, & Hume, 2000; Humphries, Newton, & Wilson, 1995; Macaluso, Isaacs, & Myburgh, 2012; Miller, 2002; Seegmiller, McCaw, 2003; Twist, Gleeson, & Eston, 2008; Van der Does, Brink, Benjaminse, Visscher, Lemmink, 2016). These undesired effects are due to high impact forces placed on the body during the landing phase of the jump (Herljac et al., 2000; Singh et al., 2013; Seegmiller et al., 2008; Van der Does et al., 2016).

Magnitude of force and rate of force development are two large factors in whether a force will cause damage to anatomic tissue (Singh, A., 2013). These factors are important for clinicians to consider when working with populations who have little experience with plyometrics and those who have physical injuries or impairments. (Miller et al., 2002) Benefits of plyometric exercise can still be achieved by the aforementioned populations, but precaution must be taken to lower impact forces.

Aquatic plyometrics are being shown to decrease impact forces of jump landings. Ruschel et al., (2016) found that completing plyometric jumping exercises in an aquatic environment, impact forces were reduced by 41.8% and time of impact was increased by 41.8%, reducing rate of impact. Similarly, Searle (2015) found that aquatic environments decreased peak force, rate of force development, impact impulse, and time to stabilization for both countermovement jumps and squat jumps. Other studies on aquatic plyometrics show little to no significant difference in desired outcomes of increased strength, power, and balance (Atanasković, Georgiev, & Mutavdzić, 2015; Robinson, Devor, Merrick, & Buckworth, 2004). Some studies have even reported increased desirable outcomes when completing exercises in an aquatic environment (Arazi, & Asadi, 2011; Colado, Garcia-Masso, González, Triplett, Mayo, & Merce, 2010). Kobak, Rebold, Desalvo, & Otterstetter (2015) found significant increases in balance, vertical jump height, quadriceps strength, and hamstring strength in individuals who completed aquatic plyometrics vs. those who completed the same exercises on land.

Clinicians seeking means of gradually increasing aquatic landing impact impulse to prepare patients for land based activities and the associated force may add external load via weighted vests. The use of weighted vests has been shown to increase plyometric outcomes in athletes (Khlifa et al., 2010; Young, 2001). Chu, & Shiner (2006) commented that using a vest is an excellent alternative to use of a barbell by beginners or rehabilitating athletes. Kamalakkannan, Azeem, and Arumugam (2011) noted that both the use of water and weights significantly increased explosive power, speed, and endurance over that of just water alone.

Plyometrics have been shown to have beneficial effects to multiple populations. Athletic populations may seek the added benefit of fluid drag to increase resistance, while other populations may desire the buoyant properties of water for decreased impact forces. When added with other variables, such as external load via weighted vest, aquatic environments may increase desired outcomes while also decreasing undesired side effects. The purpose of this study is to compare the effect of differing loads in aquatic conditions to the standard land based plyometric countermovement vertical jump on peak impact force, rate of force development, and impact impulse.

Methods

Participants

Twenty four healthy NCAA Division I female athletes (12 gymnasts and 12 soccer players) between the ages of 18-23, were asked to volunteer as participants. To meet inclusion criteria, participants reported being injury free and having no surgical operations three months prior to data collection that would prevent them from completing a plyometric countermovement jump. All participants received a printed list of requirements and signed informed consent waivers. All procedures and letter of informed consent were approved by the Utah State University Office of Research and Graduate Studies Institutional Review Board (IRB# 4967 amendment #2). There was no participant attrition during this study.

Procedures

Participants performed three countermovement jump trials in two environments (land and xiphoid process (XP) submersion) with four load conditions (body weight (BW), BW+10%, BW+20%, and BW+30%), additionally three more countermovement jumps were performed at submersion level of greater trochanter (GT) for BW trial only. There was a total of twenty seven countermovement jumps performed in this study. External loads were calculated based on participants measured static BW on land. All measurements and data were collected using a waterproof force plate (AMTI, Model OR6-WP; Columbus OH) that was positioned in the center of a height adjustable floor of an aquatic treadmill (Hydroworx 2000; Middletown, PA). Participants were offered the option to complete a small warm up of free BW squats and practice countermovement jumps.

Land trials were completed by recording the participant's static mass, followed by a single countermovement jump trial in each load condition. For aquatic trails participants were submerged in a heated pool (36.6^{o}c) to the level of xiphoid process, then greater trochanter of the femur. Miller, Cheatham, Porter, Ricard, Hennigar, and Berry (2007) found no significant difference in concentric power or average concentric force produced between participants submerged either chest or waist deep. Static mass and trials were then recorded. Additional load was added to participants via weighted vest (MIR Vest Inc. San Jose, CA). Load was added to participants in increments of 1.4 kg (3 lbs.) therefore, each trial load was rounded to the nearest 1.4kg increment. Added load did not exceed the mass capacity of the vest (27.2kg (60lbs)). Vest was removed from participants to add mass for proceeding trial.

Trials were accepted when participant's hands remained on hips for the entirety of the jump, and both feet landed simultaneously within boundaries of the force plate and remained on force plate until stabilization was achieved. Trials that did not meet criteria were repeated.

Data Collection

Data collection was triggered manually, then collected using Netforce software (AMTI; Columbus, OH) at a duration of 10s (1000Hz sampling rate with 25N threshold). Data sampling began on participant's verbal readiness acknowledgment, approximately three seconds before countermovement jump initiation. VGRF were measured in newtons and saved as raw data.

Data Analysis

Peak impact force was calculated taking the highest force achieved during landing phase of each trial. Impact impulse is the measurement of the change in momentum due to the force of the impact. Impact impulse was calculated using the middle Reimann sum formula for area under the force-time curve, then the participant's static trial weight was extracted from the formula. This equation produces the impact impulse relative to static trial weight (Figure 1). The formula was input into Microsoft Excel software and variables were inserted to ensure speedy and accurate calculations were performed. Rate of force production for the first 5ms was calculated using the equation ($\partial F/dt$) in excel.

Mean peak, rate of force development, and impulse were taken for each variable and were used for data analysis. A repeated measures ANOVA (2sport x 9 environmental conditions) was used to analyze and determine if significant interactions existed ($\alpha = p \leq 0.05$). If ANOVA reported signs of significance a Duncan's Least Significant Difference (LSD) post-hoc test was run to determine where significant differences were found.

Results

Peak Impact Force

There was no significant difference for peak impact force on land or in water based on sport. Aquatic conditions produced statistically lower peak forces than jumps on land. Applying additional external load to participants made no significant difference on land. There was, however, a significant difference in loaded trials when participants were submerged to their xiphoid process. These differences occurred at every increasing load except between XP+10 and XP+20($p=0.68$). Submersion depth made a significant difference on impact peak force ($p\leq 0.000$) with less peak force recorded the more the participants were submerged.

Rate of Force Development

There were no signficant differences in rate of force development based on sport on land or in water. All aquatic jumps were statistically lower than the lowest recorded rate for land based jumps. Additional external load did not create significantly different rates of force development on land. There was a significant difference in rate of force development when comparing additional external load while submerged to xiphoid process($p\leq 0.000$). XP+10 was not significantly different than either XP(BW) or XP+20. However all other aquatic loaded conditions were significantly different. There was a signficant difference in rate of force development based on submersion level ($p= 0.000$) with rate decreasing as the participants depth increased.

Impact Impulse

There was no significant difference in impulse based on sport on land or in water. Jumps performed in different environments were significantly different with land based jumps statistically higher than all jumps performed while submerged to xiphoid process or greater trochanter. Application of external loads produced significantly different results on both land ($p=0.000$)and when submerged in water to xiphoid process($p\leq 0.001$). Increasing external load on land significantly increased the impulse for every incremented step. While submerged to xiphoid process increasing external load statistically increased impulse for every increment until XP+30. XP+30 did not statistically differ from XP+10 or XP+20.

Discussion

The purpose of this study was to compare the effect of differing loads in aquatic conditions to the standard land based plyometric countermovement vertical jump on peak impact force, rate of force development, and impact impulse. Understanding the effect of increased load in aquatic environments can be a useful tool for rehabilitation clinicians attempting to progress patients back to physical activity, or developing exercise programs for patients with a variety of different neuromuscular disorders. Results may also be informative to populations attempting to increase power and training load while decreasing stress placed on body tissue via the landing phase of plyometric jumps.

The environment results in this study agree with Searle (2015) study comparing plyometric landings on land vs. in waist deep water for young and middle aged adults. Searle (2015) found significantly lower peak force, rate of force development, and impulse when comparing only body weight countermovement plyometric jumps. The significantly lower peak force, rate of force development, and impact impulse are due to the previously discussed aquatic characteristics of buoyancy, fluid drag, and increased viscosity. Ruschel et al. (2016) found similar results where the peak impact force of drop jumps performed by athletes at the University of State of Santa Catarin dropped by 41.8% when performed on land vs in water. Ruchel et al. (2016) findings were similar to the results in this study, where peak force of impact dropped by 50.7% when performing a countermovement jump while submerged to xiphoid process.

Donoghue, Shimojo, and Takagi (2011) study on University of Tsukuba swimmers with little to no experience in plyometrics showed a 40% decrease in impact peak force, a 50% decrease in impact rate of force developed, and a 34% decrease in impact impulse when performing countermovement jumps in aquatic environments over performing them on land. Donoghue et al. (2011) submerged their participants their waist, which is not as deep as the xiphoid process data in this study, yet not as shallow as the greater trochanter data. The findings in this study for impact peak force depict the similarities found in their data (table1). Since the participants in Donoghue et al. (2011) study are relatively inexperienced with plyometric exercises, and the participants in this study are very well versed in plyometric exercises, it may be that the data in this study is representitive of more than just elite level plyometric athletes.

This study was to address the possibility of utilizing increasing external load via a weighted vest in conjunction with previously mentioned properties of aquatic environments to increase When increasing external load on land, there was no significant change in landing peak force. This may be due to our participants being elite caliber athletes who may subconsciously implement different landing techniques due to prior learned experiences landing with differing external loads. This agrees with Janssen, Sheppard, Dingley, Chapman, and Spratford (2012) study on utilizing weighted vest to increase external load. Janssen et al. (2012) found no significant increase in neither peak vertical ground reaciton force nor vertical rate of force development when adding a weighted vest to junior national team men's volleyball players in Australia. Janssen et al. (2012) used a vest loaded at 9.89kg or about 11.4% of average participants resting mass. However, when submerged to the xiphoid process participants experienced significantly increased peak landing forces for almost every increased load in a linear fashion (Figure 2). This agrees with the previous hypothesis about learned experiences since, although being elite level athletes, the participants in this study have little to no experience completing countermovement jump landing tasks in aquatic environments. When submerged to the level of participants GT peak impact forces were statistically higher than every XP submerged trial except XP+30%.

Rate of force development seems to not be significantly altered by increasing load on land. There existed only one significant difference between the land based trials which was a slight decrease between the BW10% and BW30%. When submerged increasing external load seemed to have an exponential effect on rate of impact force development (Figure 3). This explains the difference in the results section, at low levels of external load the resultant force would not vertically rise enough on the exponential curve to be significant. However, at higher loads it does not require such a drastic change in external load to produce a significant difference. This follows the principle of the force/velocity exponential curve used in muscle physiology (Figure 4). If this is true then more research is needed to determine what the exact amount of incremental weight added would be required at low external load to produce significant differences in aquatic settings. This would also suggest future studies be weary of increasing load amounts at high levels of external load. GT submersion was significantly different from all XP submersion trials except XP+30%.

Peak force and rate of force development both have insignificant differences between the GT submersion trials and XP+30% submersion trials. Participants do, however, have a significantly higher measured static weight for the XP+30% over GT submersion ($p \leq 0.000$). This may be explained by the increased drag of deeper submersion decreasing landing velocity enough to match that of lesser submersion. More research is needed in this area to determine if GT submersion reflects landing properties of XP+30% submersion.

Increasing external load increased the impulse of every land based trial, this was the only variable to produce a significant difference in land based trials. Since impact impulse is the area under the force time curve, and neither peak force nor rate of force development significantly differed between land trials, the increase in impact impulse is due to the participants adopting a landing technique which required a significantly longer time to return their overall mass back to static trial weight. This landing technique can be produced via increasing changed in segmental angles, or consciously producing increased eccentric force to decrease segmental angular velocity, landing techniques implemented when increasing height of drop landing. (McNitt-Gray, 1991)

When submerged to XP participants experienced significantly higher impact impulse for each increasing external load besides XP+30%, which decreased from XP+20% but was not significantly different from XP+10% or XP+20%. GT submersion did not significant alter impact impulse from any XP submersion trials, but was significantly lower than all land based trials.

Decreased peak impact force and rate of impact force development may decrease risk of acute injury during plyometric countermovement jump landings. In addition, lowering impact impulse may serve to protect participants, patients, and clients from injuries associated with overuse and overtraining. Rehabilitation clinicians might consider these findings when implementing external load to aquatic therapy due to the overload principle of physiology. Gradually increasing the peak impact force and rate of force development back to static land BW levels would allow patient's body tissue to develop necessary strength while protecting the tissue from acute trauma, and overtraining. Along the same principle, these findings, in conjunction with findings from Gollofon (2016) study showing decreased ability to overcome increasing loads in aquatic conditions, may be implemented by fitness professionals and strength and conditioning coaches as a safe way to increase training load while protecting clients from acute injury risk and overtraining.

This study contained several limitations. The vest used to apply external load was limited to increments of 1.4kg, making exact percentages of the relatively low mass participants difficult, however, external load was always within 1.3% of desired load. The increased surface area produced by the vest may contribute to increased drag through XP submersion trials, lowering participants landing kinetics. Controlled countermovement jumps were the only plyometric exercise utilized in this study and were completed as single trials with substantial rest periods between trials. This does not replicate plyometric exercises generally prescribed by fitness professionals who design exercises to be repetitive with little recovery time between trials.

Future studies should focus on the landing kinetics of other plyometric exercises, differing participant populations, and different levels of submersion with external load. Kinematic factors and their influence on landing kinetics between environments and differing loads should be studied before making any concrete statements on landing techniques implemented. External load added to participants in aquatic environments may produce enough significant difference in landing kinetics to induce overload principle. Therefore, a study separating participants into gradually increased load aquatic exercises and BW only aquatic exercises should look into the differences in rehab time for return to land based plyometrics.

Conclusion

Results of this study indicate that use of an aquatic environment significantly decreases the landing peak force, rate of force development, and impact impulse of plyometric countermovement jump landings. Additionally, increasing external load placed on participants via weighted vest significantly increases the landing peak force, rate of force development, and impact impulse of plyometric counter movement jump landings in aquatic conditions. Aquatic properties such as drag and buoyancy may be able to decrease landing kinetics, thereby reducing risk of body tissue damage. Utilizing a device to increase external load placed on participants may be able to induce overload principle and provide linear progression into land based plyometrics for several differing populations.

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Figure 1: Impact Impulse Relative to Participants' Static Trial Weight

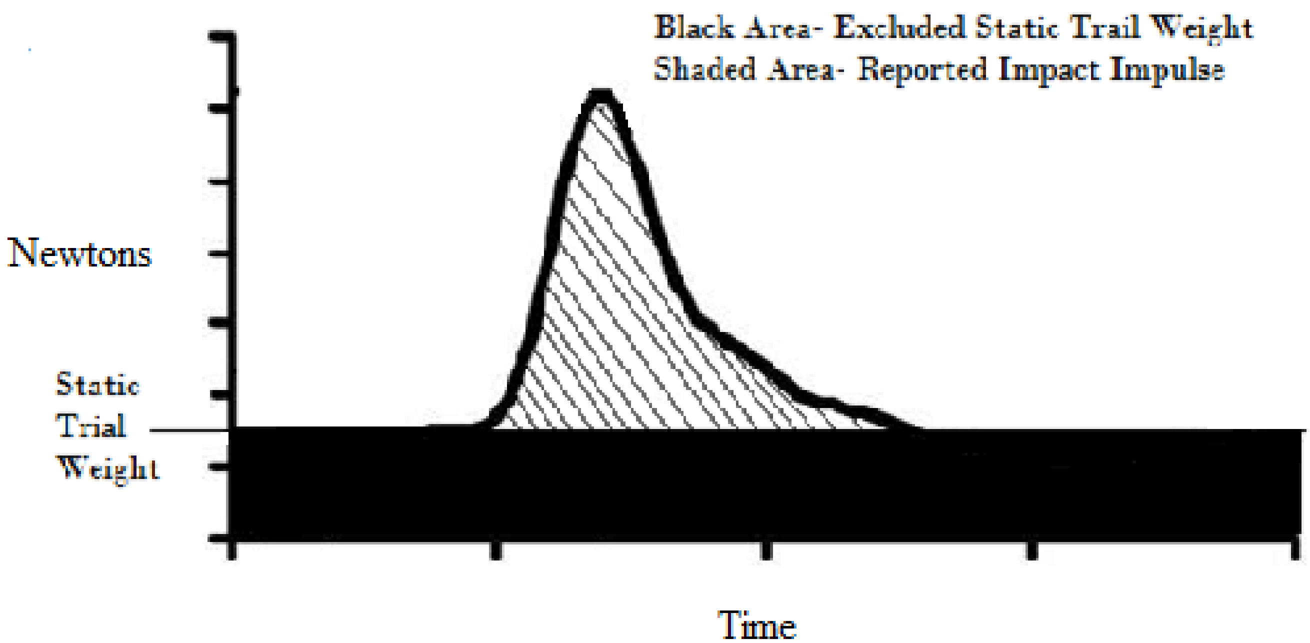

Figure 2: Means of Peak Force

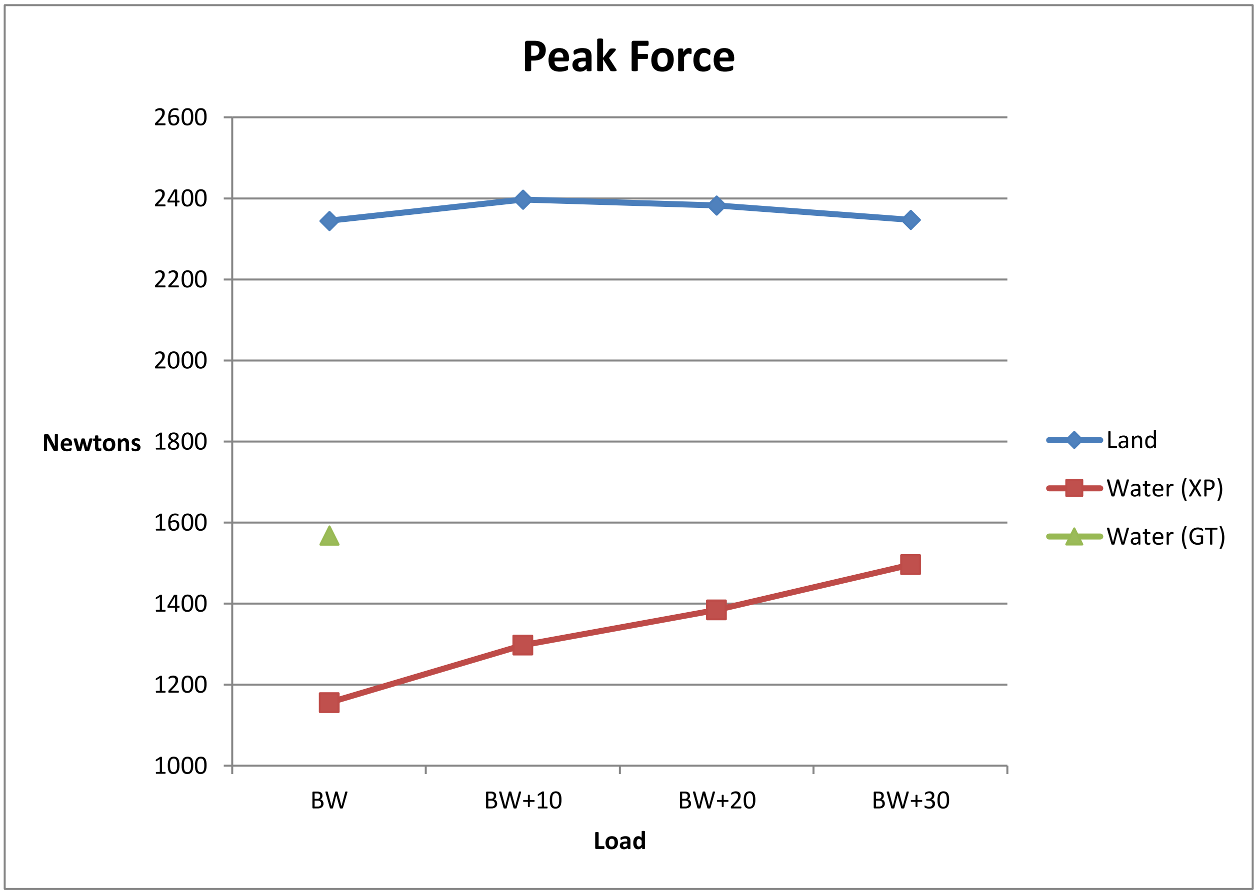

Figure 3: Means of Rate of Force Development

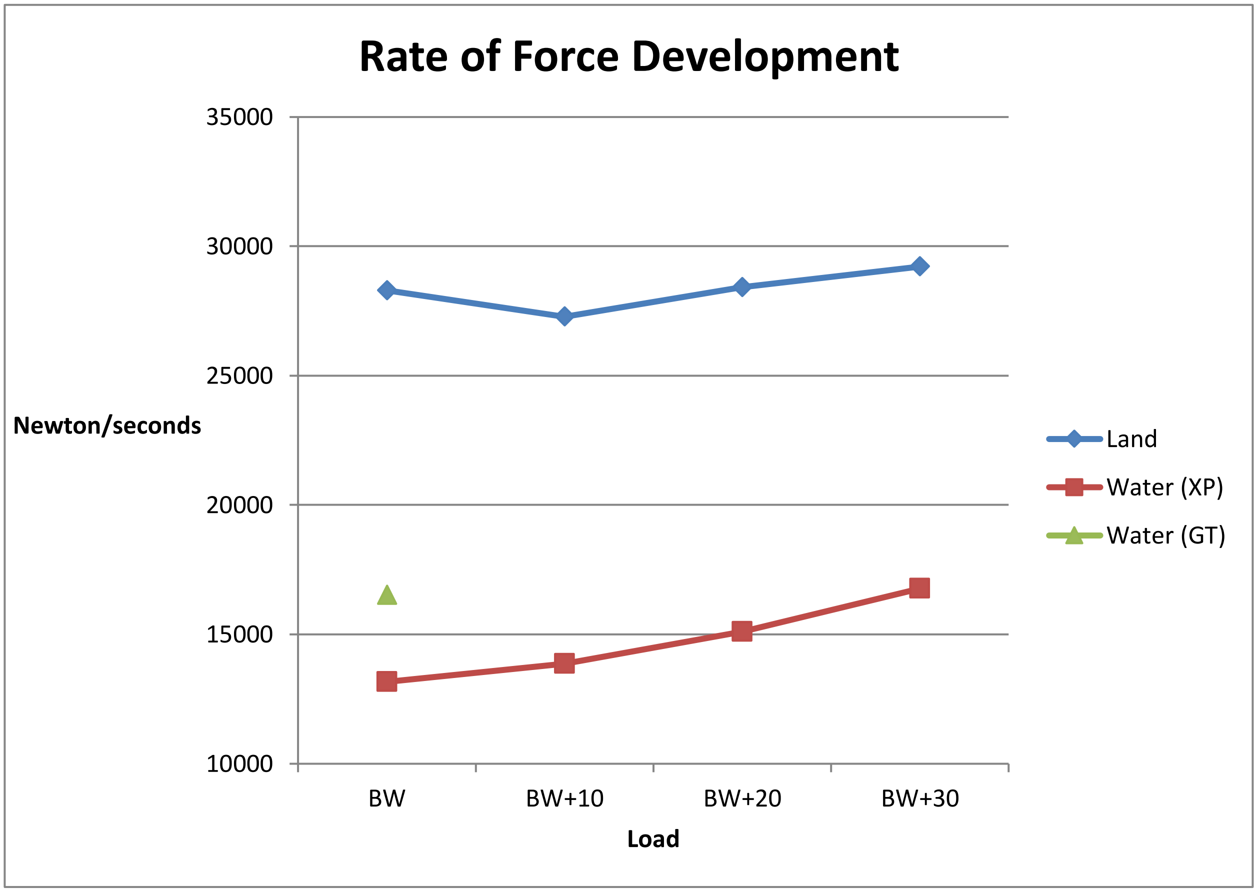

Figure 4: Means of Impact Impulse

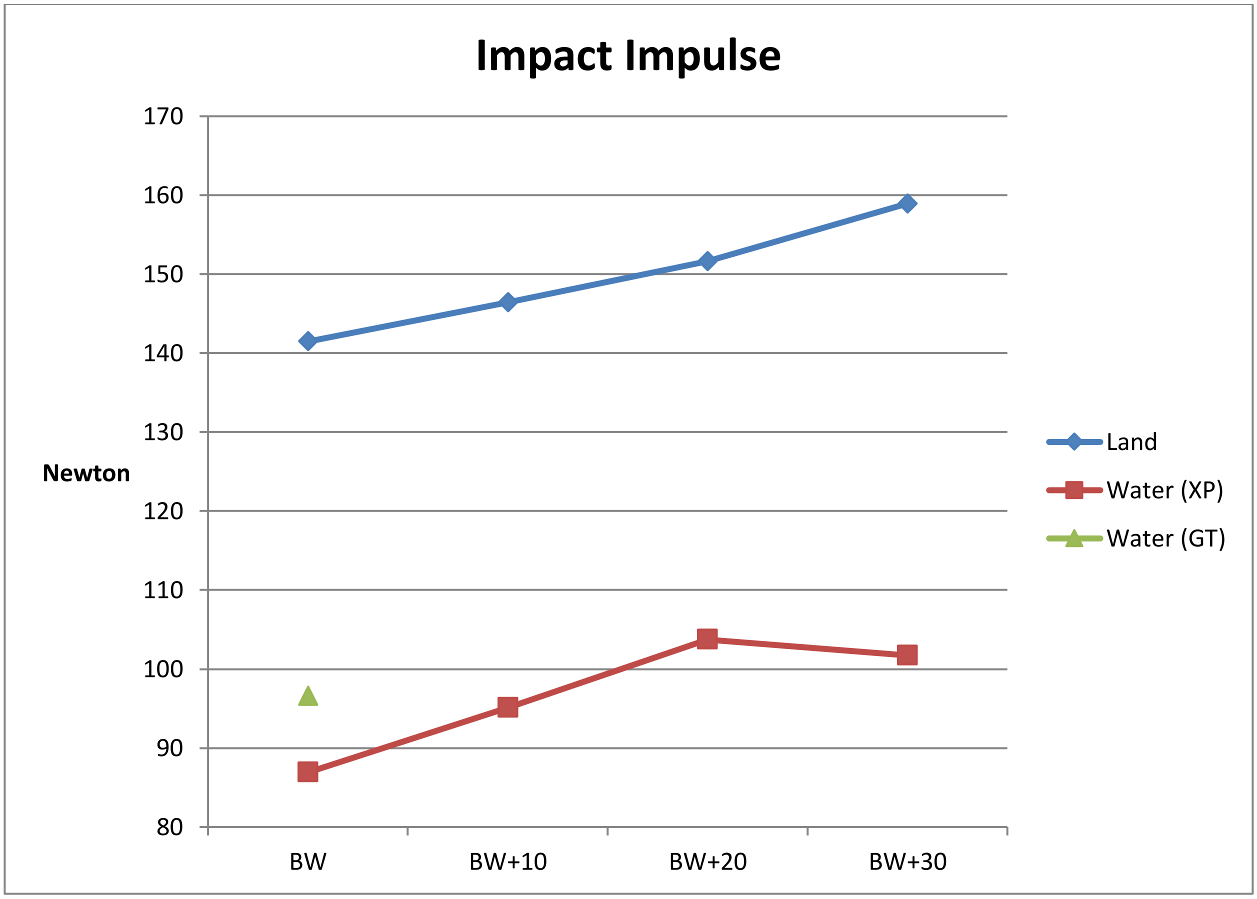

Table 1: Percent decrease from land to water

Percent Decrease From Land to Water

	Donoghue	XP	GT
Peak Force	40%	50.7%	33.1%
Rate of Force Development	50%	53.5%	41.6%
Impulse	34%	38.6%	31.7%

Table 2: Comparison of Land based Kinetics to Other Studies

Countermovement Jump Kinetics on land: Normalized to Body Weight

	Jensen	Searle	Donoghue	Beachem
Peak Force Land (N/BW)	3.71 ± 0.95	4.0 ± 2.0	5.55 ± 1.40	3.84 ± 0.72
Rate of Force Development	108 ± 46.14	60 ±35	134 ± 48	46.24 ±10.94
Impulse		0.6 ± 0.18	0.77 ± .05	0.81 ± 0.01