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Comparison of Propulsive Power During Loaded Countermovement Jumps in Division One Female Soccer Players and Gymnasts

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COMPARISON OF PROPULSIVE POWER DURING LOADED

COUNTERMOVEMENT JUMPS IN DIVISION ONE FEMALE SOCCER PLAYERS

AND GYMNASTS

by

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Abstract

Aquatic training has become more prevalent as a means of training power, and provides unique features such as buoyancy and inflicting less stress on the body than traditional land based training. **Purpose**: The purpose of this study was to assess absolute and relative peak propulsive and mean power in loaded countermovement jumps (CMJ) performed on land and in water in Division I soccer players and gymnasts. **Methods:** Twenty-four Utah State University soccer players (N=12) and gymnasts (N=12) performed randomized countermovement jumps in eight conditions (Land BW, BW+10%, BW+20%, BW+30%; Chest-height water BW, BW+10%, BW+20%, BW+30%). Peak power (PP), relative peak power (rPP), mean power (MP), and relative mean power (rMP) were examined for all jumping conditions. A 2 (sport team) by 2 (environment) by 2 (load) repeated measures ANOVA was used to evaluate main effects and interactions. **Results:** PP, rPP, MP, and rMP were not significantly different for increased loads within the same environment. When compared to jumps performed on land, all four variables were significantly higher for water conditions ($p<0.001$). Mean values for each environment were 3,845.9 ± 30.2 W, 60.4 ± 0.5 W/kg, 1,605.6 ± 54.1 W, and 25.2 ± 0.8 W/kg for PP, rPP, MP, and rMP respectively for land, and 6,829.3 ± 405.7 W, 326.9 ± 18.8 W/kg, 2,659.8 ± 118.8 W, and 126.9 ± 5.5 for water. Sport team affiliation had a significant effect for rPP, MP, and rMP ($p<0.03$), and an interaction effect for environment*sport was also present for all four variables tested ($p<0.01$). An aquatic environment provides resistance that can result in higher power production than on land, making it ideal training environment for athletes.

INTRODUCTION

Power production is a key element in sports, but many training methods place great stress on the body (Donoghue, Shimojo, & Takagi, 2011). Accordingly, aquatic training as a means of training peak propulsive power (PP) is becoming more prevalent in research (Arazi & Asadi, 2011; Colado, Benavent, Alakhadar, Madera, Gonzalez, & Tella, 2009; Louder, Searle, & Bressel, 2015; Miller, Berry, Bullard, & Gilders, 2002, Miller, Cheatham, Porter, Ricard, Hennigar, & Berry, 2007; Ploeg, Miller, Holcomb, O'Donoghue, Berry, & Dibbet, 2010; Robinson, Devor, Merrick, & Buchworth, 2004; Searle, Louder, & Bressel, 2015; Stemm & Jacobson, 2007; Triplett, Colado et al., 2009; White & Smith, 1999). Power plays a role in many sports, including soccer and gymnastics. Peak Power can be measured using a countermovement jump (CMJ), and has been established as a valid and reliable assessment tool (Markovic, Dizdar, Jukic & Cardinale, 2004; Sheppard Cormack, Taylor, McGuigan, & Newton 2008). The measurement of PP using a CMJ generates a power curve, displaying decreasing PP as load increases (Haff & Nimphius, 2012; Kawamori & Haff, 2004; Sheppard et al., 2008; Stone et al, 2003).

Muscular power is a primary factor in sport performance (Cormie, McCaulley, Triplett, & McBride, 2007). Power, expressed in watts, is defined as the product of force (Newtons) and velocity (meters/second) (Haff & Nimphus, 2012; Cronin & Sleiver, 2005). A maximum height CMJ can be utilized to measure power (Markovic et al., 2004; Sheppard et al., 2008). Baker et al. (2011) compared power produced during CMJs and 1 repetition maximum (1RM) back squat, and reported that peak power was achieved at 55-

59% 1RM. Additionally, Cormie et al. (2007) reported PP occurred at 56% 1RM back squat, but was not significantly different from other loads.

Aquatic training environments offer unique features, including buoyancy, fluid drag, and hydrostatic pressure. It has been reported that compared to land, plyometric exercise performed in water results in less muscle soreness (Robinson et al., 2004), reduced impact forces (Triplett et al., 2009; Colado et al., 2010; Ebben et al., 2010; Donoghue et al., 2011; Alberton et al., 2013), and increased rate of force development (Triplett et al., 2009). When performing a CMJ in water, research has shown increased ground reaction forces (GRF) and decreased impact forces when compared to on land (Colado et al, 2009; Donoghue et al., 2011; Louder et al., 2015; Triplett et al. 2009). Increased GRF can be attributed to the jumper requiring additional force to overcome the resistance created by fluid drag (Arazi & Asadi, 2011; Colado et al., 2009; Louder et al., 2015; Miller et al. 2002; Ploeg et al., 2010). Apparent mass is reduced in water due to buoyancy, resulting in lower impact forces (Arazi & Asadi, 2011; Miller et al., 2007; Robinson et al., 2004). When performing jumping tasks in water, more force is required to overcome the drag forces on the takeoff, yet impact forces are decreased on the landing, creating an optimal environment for training.

Previous research has shown increased training effects for aquatic exercise interventions when compared with land, including increases in strength, agility, and power development (Arazi & Asadi, 2011; Ploeg et al., 2010; Colado et al., 2010; White & Smith, 1999; Whitehill et al., 2010). After an 8-week aquatic exercise intervention, Arazi and Asadi (2011) reported significant improvements in vertical jump height, broad jump, and agility in semi-pro basketball players, while players assigned to an identical land based intervention only had significant improvements in vertical jump. Ploeg et al. (2010) documented superior improvements in jump height, knee flexion power, and knee extension power following a 6-week aquatic intervention when compared with a land-based intervention in young adults. Following 8 weeks of an aquatic exercise training program, Colado et al. (2010) reported greater improvement in squat jump mechanical power and reduced body fat percentage in young adults when compared to a land based program. White and Smith (1999) reported increased muscle strength in the lower extremity in young adults after an 8-week aquatic training program. When comparing six different measures of agility and balance in competitive athletes after a 9-week aquatic problem with an identical land based program, Whitehill et al. (2010) reported a 27 percent average improvement in the aquatic group, compared to just a 4 percent average improvement in the land based group. This evidence suggests that training in aquatic environments may have increased training effect on many aspects of athletic performance.

Deepening the understanding of how to best train female athletes requires attention to two specific gaps. First, there is limited knowledge of how to train peak power in both soccer players and gymnasts. Because peak propulsive power is a determinant of athletic performance (Cronin & Sleivert, 2005; Haff & Nimphius, 2012; Kawamori & Haff, 2004), it is vital to examine the best training method to develop power in these female athletes. Second, there is no research comparing PP or relative PP (rPP) and mean power (MP) or relative MP (rMP) in female soccer players and gymnasts. In order to understand differences between the two groups and how to implement training programs, it is essential that the groups be compared. The purpose of this study was to compare peak propulsive power and mean power in female division I soccer players and gymnasts, both on land and in water.

This study will test for three hypotheses; 1) PP, rPP, MP, and rMP will significantly decrease as load increases; 2) PP, rPP, MP, and rMP in the water will be greater than PP, rPP, MP, and rMP on land; and 3) There will be a significant difference between the sport teams- soccer players and gymnasts.

METHODS

Twenty-four apparently healthy Division I female soccer players and gymnasts aged 18-22 years were recruited from Utah State University through personal contact by the investigator. In order to participate, subjects reported they were free from any lower extremity orthopedic injury, and have not had recent (within 3 months) surgeries preventing them from safely completing countermovement jumps with loads. Subjects were informed of the obligations of the study, and were required to read and sign an informed consent form. All procedures were submitted to and approved by the Institutional Review Board (IRB# 4967 Amendment #2). There was no participant attrition for the duration of the study.

PROCEDURES

Subjects performed countermovement jumps in eight different conditions, with three trials at each in a randomized order. The two environments examined, land and water, were each utilized with four conditions: unloaded, 10%, 20%, and 30% bodyweight (BW). For trials in the aquatic environment, subjects were submerged to their xiphoid process. Bodyweight was measured on land, and loads were added to the land and water trials accordingly. Each participant was given the option of an unrestricted number of practice jumps in each condition, until they reported that they felt comfortable and were able to give their best effort.

Countermovement jumps were performed on a waterproof force plate (AMTI, Model OR6-WP; Columbus, OH) placed on an adjustable-height underwater treadmill (Hydroworx 2000; Middletown, PA). Subjects' apparent mass was measured with the force plate prior to completing any of the trials. Depth of the countermovement was self-selected, and subjects were instructed to "jump as high as possible using your natural jumping method."

In the loaded conditions, loading was achieved using a weighted vest (MIR Vest Inc.; San Jose, CA). Due to the limitation of the vest model, weight of the load was rounded to the 1.4 kg (3 lb) increment nearest the weight required to achieve the percentage-loaded weight for each subject. Between conditions, a rest period of 2-3 minutes occurred as the load of the vest was adjusted.

Trials were accepted when the subject performed a CMJ while keeping their hands on their hips throughout the entirety of the jump, and both feet landed simultaneously on the force plate. Jumps that failed to meet the criteria were repeated.

Data Collection

Data was collected and recorded using Netforce software (AMTI; Columbus, OH) for 10s (1000 Hz sampling rate with 25 N threshold). Collection and recording was triggered manually, and began approximately three seconds before initiation of the CMJ. Vertical GRF (N) values were saved as raw data. GRF of the propulsive phase of each CMJ, along with apparent mass of each subject was uploaded into Microsoft Excel (Microsoft Corp.; Redmond, WA). The propulsive phase was defined as all GRF values above apparent mass between the initiation of the jump and when the subject became airborne (Hori et al. 2009; Louder et al., 2015). Peak propulsive power was the highest value achieved during the propulsive phase, while mean power was the average of all obtained values during this phase. The following equations were used to calculate power at each time point (Louder et. al, 2015; Nardoni 2015):

Equation 1. (Force)(time)/apparent mass = (acceleration)(time)

Equation 2. $\int$(acceleration)(time)=Δvelocity

Equation 3. $\text{Power}_t = (\text{force}_t)(\Delta\text{velocity}_t) = (\text{force}_t) \int_0^t[(\text{acceleration})(\text{time})]$

DATA ANALYSIS

For each condition, the average of the three trials of CMJs was used for analysis. Independent variables included environment (land or water), load (unloaded, 10%, 20%, and 30% BW), and athlete type (gymnast or soccer player). Dependent variables were absolute peak propulsive power (PP) and absolute mean power (MP). To account for each subjects' mass, relative peak propulsive power (rPP) and relative mean power (rMP) were also calculated, and expressed in W/kg. Land weight was recorded on the force plate during quiet standing. In water, apparent weight was recorded while each subject was submerged to the xiphoid level. A General Linear Model repeated measures (2 (Sport) x 2 (Environment) x 4 (Load)) ANOVA (SPSS 23, Chicago IL) was used to determine if any significant main effects and interactions were present. Sphericity for all four dependent variables were tested and failed, so the Greenhouse-Geisser adjustment was employed. When necessary, post-hoc comparisons were performed using Duncan's Least Significant Difference (LSD) test, employing the Greenhouse-Geisser method for calculated Mean Square error and degrees of freedom. The level of confidence was set at $p<0.05$.

Results

Load Main Effect

The main effect for load did not significantly change any indices of propulsive power, thus rejecting Hypothesis 1.

Environment Main Effect

The main effect for environment was significant for PP ($p< 0.001$ $F=267.196$ $df=1$), rPP ($p<0.001$ $F=728.724$ $df=1$), MP ($p<0.001$ $F=161.98$ $df=1$), and rMP ($p<0.001$ $F=494.79$ $df=1$). At comparable loads, all water conditions were significantly greater than all land conditions, supporting Hypothesis 2.

Sport Team Main Effect

The main effect for sport team was significant for rPP ($p<0.022$ $F=5.429$ $df=1$), MP ($p<0.01$ $F=9.128$ $df=1$), and rMP ($p<0.001$ $F=15.310$ $df=1$). At comparable loads in the water environment, the soccer players had significantly higher power production for three of the four variables, accepting Hypothesis 3.

Environment*Sport Interaction

The interaction effect of environment and sport team was significant for PP ($p<0.005$ $F=8.360$ $df=1$), rPP ($p<0.01$ $F=8.467$ $df=1$), MP ($p<0.001$ $F=16.069$ $df=1$), and rMP (rMP: $p<0.001$ $F=18.373$ $df=1$). The LSD post-test revealed that the significant interactions for all four variables were due to significant differences between sports for the conditions in water at the bodyweight and bodyweight+10% loads. Additionally, the water BW+20% load was significantly different for MP, and all four conditions in water were significantly different for rMP. All significant differences are reported in Tables 3-6.

DISCUSSION

This study demonstrated that regardless of added load, greater mechanical power is created when performing a CMJ in water when compared to land. This held for all variables: PP, rPP, MP, and rMP. This result supports previous research in our laboratory demonstrating greater absolute and relative PP and MP in water than on land in active male subjects of similar age to the present study (Louder et al., 2015, Nardoni, 2015). In the recent study, across all incremental loads, PP and MP produced on land were only 56.5 and 60.4% of that produced in water, respectively. Nardoni (2015) reported a similar effect, with both absolute and relative PP and MP for land conditions producing an average of 51.5 and 52.8% of that produced in water, respectively. Louder et al. (2015) reported that when comparing 12 male adults in an unloaded CMJ on land and in water submerged to the xiphoid process, PP on land was an average of 52.7% of that in water. The slighter greater ratios between land vs water in the present study may reflect a difference due to gender, as this was the first study using females. Although the females were well trained and conditioned athletes, a small difference in body composition may influence the buoyancy of the female subjects in water. A post hoc review of apparent mass in water compared to land for this and earlier studies may provide insights as to whether this may have been a factor. The present study found that subjects' apparent mass in water was 33.2% of that on land. Nardoni (2015) reported a similar ratio, with apparent mass in water being 32.3% of that on land in male subjects. Regardless, CMJs in water have consistently produced power outputs that are approximately 80-100% greater than land.

Increasing loads on land did not significantly impact the indices of power during CMJs for either sport team. One explanation for this lack of significance is with well-trained and conditioned subjects, even adding up to 30% of BW through the use of a weighted vest, a greater GRF may be generated during the propulsive phase of the CMJ, yet take a longer period of time. The resultant propulsive peak and mean power calculations would therefore be comparable due to the increase in time. An examination of the GRFs and time during the propulsive takeoff phase would provide further insights into these apparent comparable mechanical power observations. Cormie et. al (2007) reported that in Division I male athletes, maximum peak power occurred at 0% 1RM of a squat jump, and significant differences in peak power were not found until loads of 27% 1RM. These findings support that reasonable loads can be overcome on land to keep indices of power consistent.

When the CMJs were performed in water, all four variables demonstrated a significant decline in power (Figures 1-4). These findings suggest that despite the observation that with loads of up to bodyweight+30%, subjects were able to maintain power output on land, but in water subjects were unable to overcome the added resistance compared to bodyweight conditions. Although buoyancy may act to aid participants in the CMJ propulsion, the drag forces created in the water were substantial, thus causing decreases in power as load increased.

Sport team affiliation demonstrated a significant difference for rPP, MP, and rMP. We hypothesized there may be a difference due to the demands of each sport, which the current study supports. Gymnasts may concentrate training more on explosive, jumping, and bounding-type movements, or incorporate them into sport specific routines. Alternatively, the CMJ is considered a general movement task, and may not be a specific movement that can accurately discriminate between these sport teams. This is supported on land, where the two teams appeared virtually identical on power indices. Finally, the generally high level of conditioning and sport training between these groups may require a greater range of test characteristics for discrimination purposes.

Perhaps the most surprising result of this study was the ability of the soccer team to produce significantly greater power outputs at the WaterBW, and Water+10% compared to the gymnasts for all four variables (see Figures 1-4). The significant difference was extended for rMP to Water+20%, and for MP to both Water+20% and Water+30%. The Water+30% condition nearly reached significance for rMP. This difference may be due to the type of training and conditioning each sport receives. Soccer players may be more buoyant than gymnasts, helping them to overcome the increased drag forces in the water. Differences in buoyancy may be due to differences in body composition and distribution of muscle mass. However, when apparent mass in chest-height water was compared with on land, the soccer and gymnastics groups have comparable values of 33.7 and 32.6%, respectively. This variable likely had very little influence on the difference seen between sport teams.

There are several limitations to this study. The subjects used were solely female Division I gymnasts and soccer players, therefore results from this study cannot be assumed for other populations. Although the subjects were familiar with the execution of a CMJ, they were unfamiliar with jumping in an aquatic environment. The weight vest used for the loaded conditions presented several limitations itself. The vest was limited to 1.4 kg increments, so the loads could not be exact to the percentage of bodyweight. However, the load was always within 1.3% of the desired weight. Additionally, because of the fit of the vest, the load was distributed around the upper torso, which is not a natural distribution of weight throughout the body. The additional surface area of the vest may have increased drag forces for jumps performed in the water. Other studies measuring power of countermovement and squat jumps used a weighted barbell across the shoulders (Baker et al., 2001; Cormie et al. 2007, Cronin & Hansen, 2005; Hansen et al., 2011; Taylor & Taylor, 2014; Sheppard et al., 2008; Stone et al., 2003). This study only reported absolute and relative mean and peak power. There may be other dependent variables (peak take off force, impulse), which could provide additional insights relative to CMJ kinetics. Finally, the subjects self-selected the depth of the preliminary squat portion of their CMJ. They were instructed to "jump as high as possible using your natural jumping method" which allowed for variance in countermovement depth between subjects, and possibly between each condition or trial. This technique was selected as it likely represents a more natural technique for the subjects, rather than imposing a specific depth. Although the present study was limited to kinetic variables related to CMJ performance, ongoing research is evaluating the kinematic comparisons of CMJ in water vs. land to determine if movement patterns differ in these environments.

Future research should focus on evaluating the kinetics of different types of jumps, other populations of athletes, and other variables related to CMJs. Kinetic variables that could be explored in different land and water environments include impulse, peak take off force, rate of force development, and rate of peak power development. Examining these variables could add to the understanding of aquatic training effects on performance. Aquatic training may result in greater performance gains due to the increase in power production. Therefore, a study that randomizes subjects into a land versus an aquatic training program is recommended.

Conclusion

CMJs produced higher absolute and relative PP and MP when performed in water when compared to on land. Soccer players were able to produce greater power than the gymnasts, particularly in water conditions. Increased loads had a greater effect on power indices when the CMJ was performed in the water, and subjects were not able to overcome the resistance as well as on land. The properties of water such as buoyancy and drag can be used as a training tool to train propulsive power in athletes, with the added benefit of aquatic exercise producing less potentially harmful impact forces on the body.

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Table 1: Descriptive Statistics for Subjects (mean ± SD)

Sport	N	Age (yrs)	Height (cm)	Weight (kg)	Years of College Experience
Gymnastics	12	19.9 ± 1.1	160.7 ± 7.9	62.2 ± 5.7	1.4 ± 1.2
Soccer	12	19.8 ± 1.0	166.2 ± 4.8	64.6 ± 6.9	1.3 ± 0.7

Table 2. Peak Power (PP, Mean ± SD), Realtive Peak Power (rPP), Mean Power (MP), and Relative Mean Power (rMP) for all conditions (mean ± SD)

Environment-Load	Sport	PP (W)	rPP (W/kg)	MP (W)	rMP (W/kg)
Land BW	Gym	3969.7 ± 671.3	63.6 ± 7.48	1669.9 ± 374.6	26.7 ± 4.5
	Soccer	3826.6 ± 607.5	59.1 ± 6.0	1726.5 ± 374.4	26.5 ± 4.0
Land BW+10%	Gym	3850.5 ± 635.9	61.8 ± 7.3	1521.3 ± 404.5	24.3 ± 5.2
	Soccer	3808.2 ± 627.6	58.8 ± 7.0	1648.1 ± 383.3	25.4 ± 4.6
Land BW+20%	Gym	3859.2 ± 514.4	62.0 ± 5.4	1520.5 ± 370.0	24.2 ± 4.3
	Soccer	3802.2 ± 675.1	58.7 ± 7.5	1635.4 ± 392.1	25.2 ± 4.8
LandBW+30%	Gym	3832.8 ± 551.7	61.6 ± 6.2	1510.7 ± 260.9	24.3 ± 3.7
	Soccer	3818.5 ± 659.9	58.9 ± 7.2	1612.9 ± 378.5	24.8 ± 4.5
Water BW	Gym	6706.7 ± 2556.3	315.8 ± 103.4	2351.3 ± 1103.7	109.9 ± 44.3
	Soccer	7823.8 ± 2533.2	377.5 ± 116.1	3220.4 ± 1149.2	155.2 ± 52.8
Water BW+10%	Gym	6288.4 ± 2038.6	297.9 ± 85.6	2194.5 ± 925.8	103.2 ± 39.1
	Soccer	7920.6 ± 2503.7	382.7 ± 114.4	3281.5 ± 1189.4	158.7 ± 55.7
Water BW+20%	Gym	6396.6 ± 2149.8	302.9 ± 87.9	2329.6 ± 1008.5	109.4 ± 41.2
	Soccer	7079.9 ± 2075.8	342.3 ± 96.2	2950.0 ± 964.1	142.4 ± 44.5
Water BW+30%	Gym	5942.9 ± 1754.6	282.9 ± 72.7	2235.2 ± 903.1	105.7 ± 38.1
	Soccer	6475.6 ± 1990.4	313.3 ± 93.3	2715.4 ± 975.2	131.3 ± 46.0

Table 3. Post-Hoc for Environment*Sport Significant Differences: PP

Environment	Gymnastics Mean	Soccer Mean	Mean Difference	Sig
Water BW	6706.7	7823.8	1117.1	0.005
Water BW+10%	6288.4	7920.6	1632.2	0.005

Table 4. Post-Hoc for Environment*Sport Significant Differences: rPP

Environment	Gymnastics Mean	Soccer Mean	Mean Difference	Sig
Water BW	315.8	377.5	61.7	0.01
Water BW+10%	297.9	382.7	84.8	0.01

Table 5. Post-Hoc for Environment*Sport Significant Differences: MP

Environment	Gymnastics Mean	Soccer Mean	Mean Difference	Sig
Water BW	2351.3	3220.4	869.1	0.001
Water BW+10%	2194.5	3281.5	1087.0	0.001
Water BW+20%	2329.6	2950.0	620.4	0.001

Table 6. Post-Hoc for Environment*Sport Significant Differences: rMP

Environment	Gymnastics Mean	Soccer Mean	Mean Difference	Sig
Water BW	109.9	155.2	45.3	0.001
Water BW+10%	103.2	158.7	55.5	0.001
Water BW+20%	109.4	142.4	33.0	0.001
Water BW+30%	105.7	131.3	25.6	0.001

Figure 1. Estimated Marginal Means of Loads for Peak Power (PP)

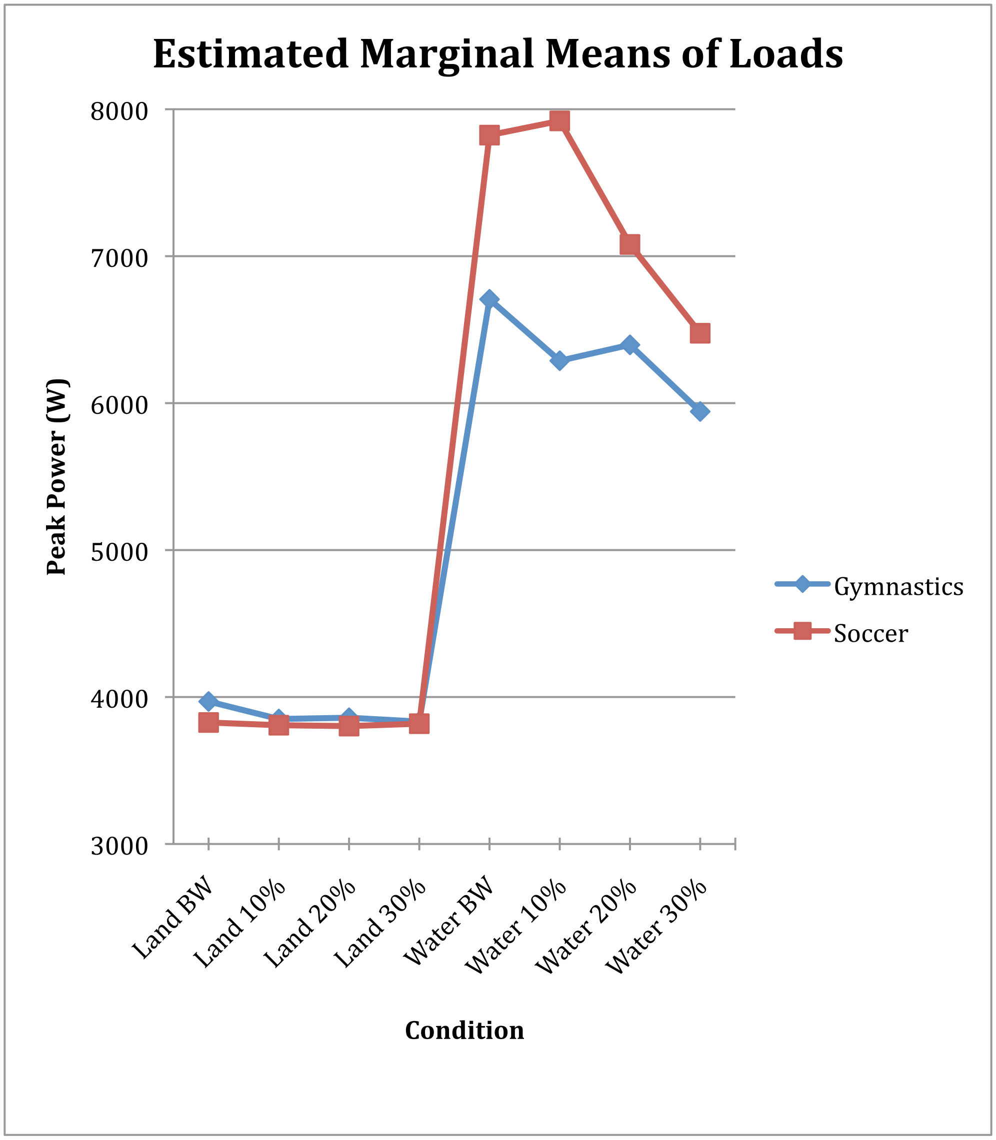

Figure 2. Estimated Marginal Means of Loads for Relative Peak Power (rPP)

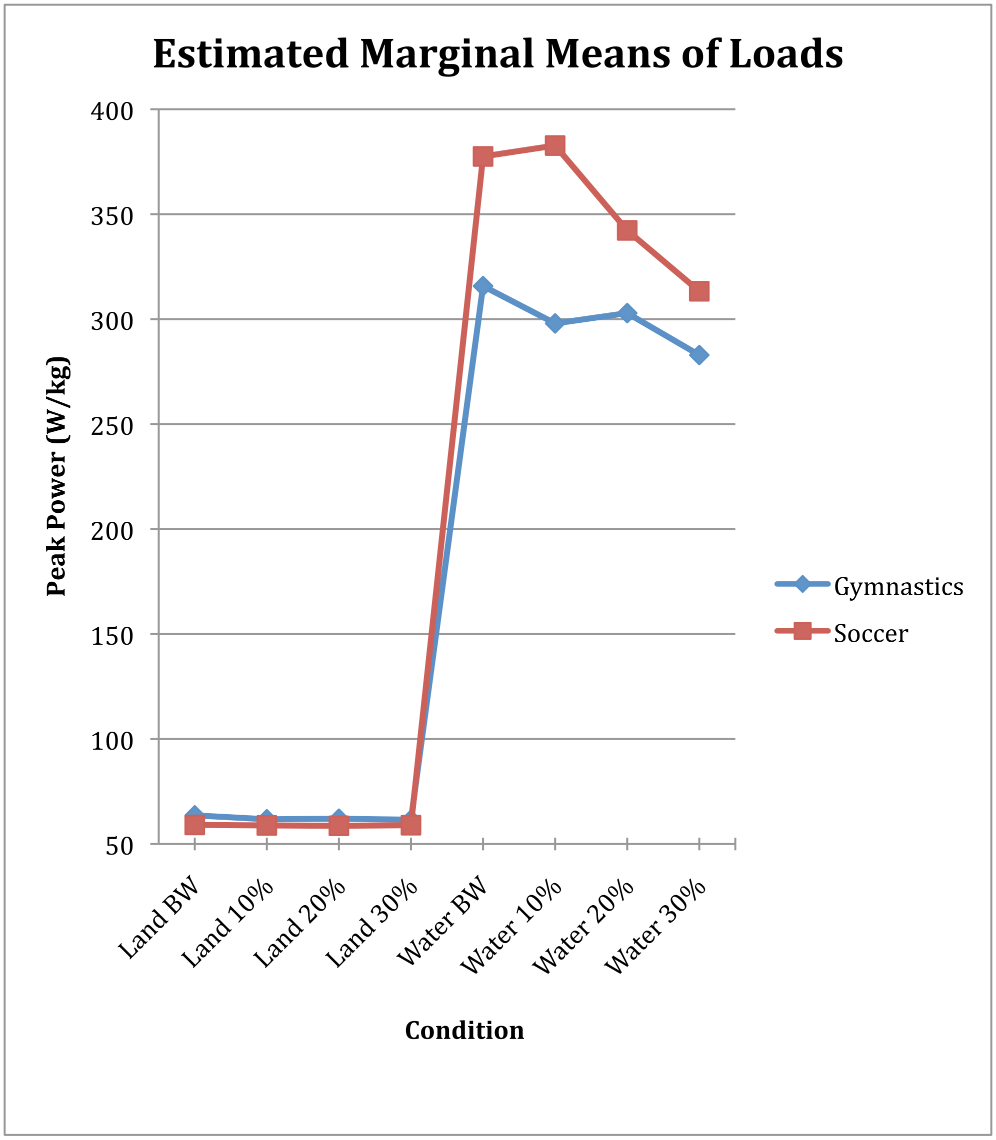

Figure 3. Estimated Marginal Means of Loads for Mean Power (MP)

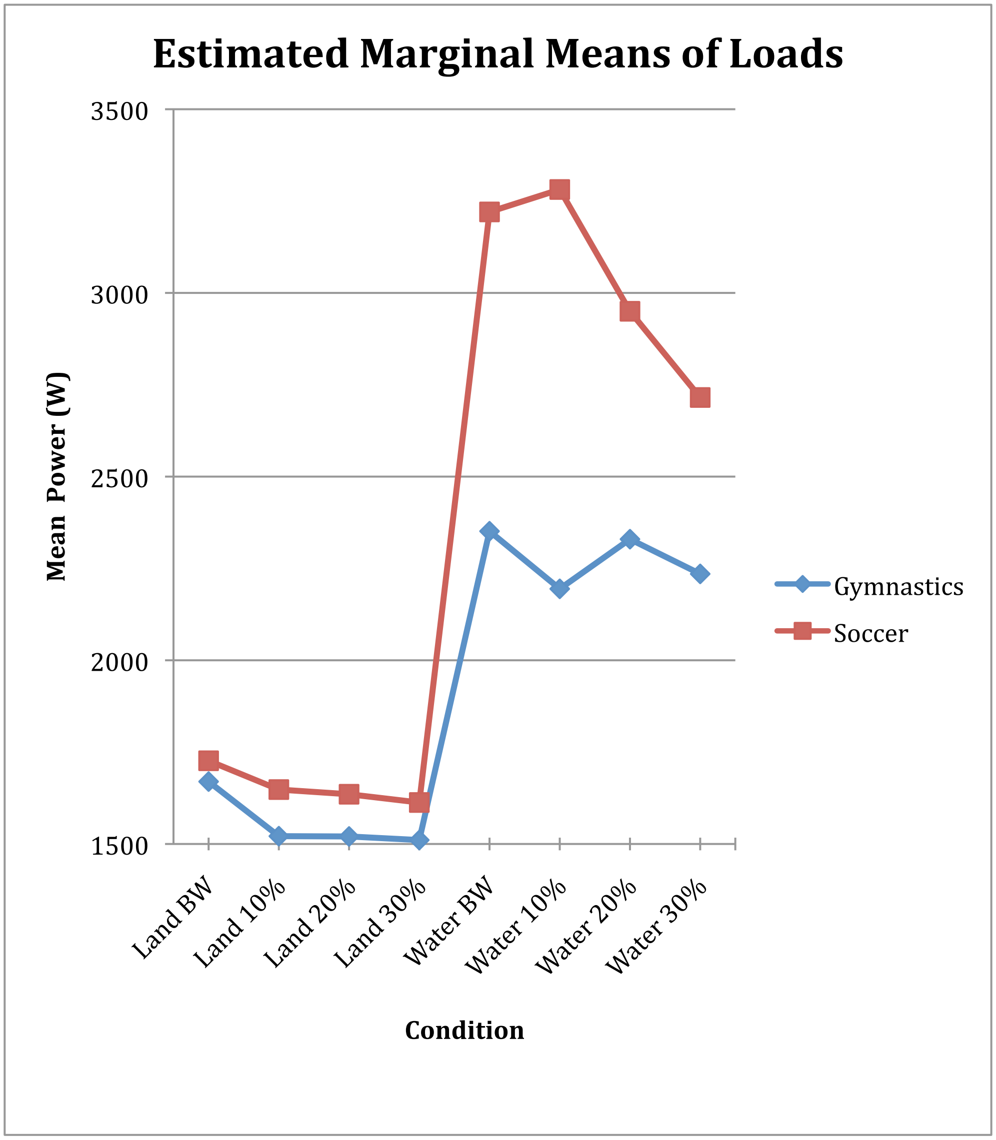

Figure 4. Estimated Marginal Means of Loads for Relative Mean Power (rMP)