STEP CHARACTERISTICS AND PHYSICAL DETERMINANTS OF REPEATED 20M-SHUTTLE PERFORMANCE IN MALE AND FEMALE ELITE FIELD HOCKEY PLAYERS.

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Repeated 20m shuttle performance in elite field hockey.

ABSTRACT

The aim of this study was to investigate the physical determinants of repeated 20m shuttle performance while exploring the role of step characteristics during the shuttle, in elite male and female field hockey players. Twenty-nine male (n = 13) and female (n=16) elite field hockey players performed 8 x 20m maximal effort shuttles with limited rest. Step characteristics including braking distance, 3rd step, 5th step and maximum velocity were calculated using measurements of stride length and frequency collected via Optojump Lower body power variables were collected from a countermovement jump (CMJ) test. Pearson's correlation coefficients and coefficients of determination were used to explore relationships between CMJ variables, repeated 20m shuttle performance and step characteristics. Stepwise linear regressions models explained variance in total time for physical determinants and step characteristics in gender groups. For female athletes relative peak power, maximum entrance velocity and braking distance predicted 85.7% of variance, for male athletes fatigue percentage, peak power and exit 5th step velocity predicted 65.8% of variance. Independent T-Tests and Eta effect sizes (ES) were conducted between upper (n=5) and lower (n=5) performers for within gender groups. Faster repeated 20m shuttle performance was associated with higher velocities entering and exiting the turn (r = -.560 to -.860), greater ability to perform braking (r = -.554) and propulsive (r = -.604) work, higher power production (r = -.716 to -.718) and higher eccentric capabilities (r = -.588 to .453) in the CMJ. For female athletes, the development of propulsive capabilities is of the highest importance, while the development of improved technique and eccentric muscle capacity during the braking phase is of highest importance for male athletes.

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CHAPTER 1: INTRODUCTION

Field hockey, like other team and field sports, is considered intermittent in nature requiring athletes to perform high-intensity efforts with short periods of rest (48,50). Repeated sprint ability (RSA) describes the ability to perform repeated sprints with minimal recovery between sprint bouts. This has been shown to be a predictor of performance in field hockey as well as other field-based team sports such as rugby, soccer and American football (2,3,5,8,19,48,57). Studies have shown that repeated high-intensity movements occur in multiple directions and are rarely performed exclusively in a straight line, this has been shown across a range of sports including field hockey (48,50), soccer (4), basketball (41, 55), volleyball (46) and tennis (31).

Change of direction (COD) can be defined as a preplanned, rapid, whole-body movement that includes a braking and propulsive force (26). COD ability is a prerequisite for successful participation in modern day sport, COD as a significant predictor of on-field performance and in American Football, and of player selection and discrimination between elite and sub-elite soccer players (18,38). The ability to change direction repeatedly has also been shown to be a predictor of high-level performance in team and court sports (7,16,21). A greater understanding of the physical and technical strategies used by players performing repeated change of direction (RCOD) is of interest to sports coaches and strength and conditioning coaches alike.

COD is closely related to other measures of athletic performance including sprinting, vertical jumping and lower body strength and power (44). Straight line sprint speed has been found to hold a negative relationship with COD (7). Strong positive relationships have been shown between straight line sprint performance and COD performance in tests comprising both multiple and single changes of direction (11,30,33,52,58). This relationship is likely because COD ability tests often involve several short distance sprints and therefore maximal speed and acceleration ability is influential (34). Hewit, Cronin, Button and Hume (2011) suggest that the ability to decelerate over fewer strides is necessary for COD performance, to do this, braking force and ground contact time must be greater. It is suggested that increased eccentric force capabilities are desirable as they allow for increased impulse to reduce velocity and momentum (23,29). The effect of acceleration and deceleration ability during COD requires athletes to have sufficient eccentric and concentric strength capabilities during the braking and propulsive phase respectively (28,29,51,54). Acceleration phases of sprinting utilise predominantly concentric muscle contractions, while deceleration phases utilise eccentric muscle contractions (23). Identifying physical and technical determinants of COD ability may aid coaches in improving performance and reducing injury risk (22).

Deceleration appears to be a factor that differentiates RSA performance from RCOD performance (53). Turner & Stewart (2013) questioned the ecological validity of RSA protocols that use straight-line sprinting as they rarely represent the typical movement patterns of team sports, and suggest the specific nature and physiological impact of COD warrants its inclusion in such tests. The findings of Dellal et al. (2010) showed that the physiological impact of intermittent shuttle sprints was substantially higher than that of intermittent straight line efforts, eliciting higher heart rates, blood lactate levels and rate of perceived exertion. Furthermore, Hader et al. (2014) found that when compared with RSA, RCOD was associated with higher blood lactate concentration, and similar decreases in lower limb EMG activation, countermovement jump, drop jump and cardiorespiratory responses. This is found despite subjects achieving lower peak velocities over equivalent distances in shuttle efforts compared to straight line efforts (20). As is evident, COD has a significant impact on the levels of fatigue that occur during RSA protocols. The causes of this fatigue warrant further investigation, as few studies have looked at RCOD performance and those that have predominantly focus on physiological fatigue markers (17,20,40) or performance fatigue (14,56). To the author's knowledge there are no current studies that have investigated the physical determinants and step characteristics of RCOD in elite performers.

Studies have shown strong negative relationships between various CMJ tests and COD tests. Relationships have been found between dominant leg unilateral CMJ height and 180° COD as well as non-dominant leg unilateral CMJ power and a 3-cone drill test (24,39). When assessing the relationship between various CMJs and COD tests, Castillo-Rodríguez, Fernández-García, Chinchilla-Minguet and Carnero (2012) found that bilateral CMJ jump height correlated with all COD tests and had the strongest relationship with 180° COD, while unilateral CMJ height in the dominant leg had the strongest relationship with 90° COD. Castillo-Rodriguez et al. (2012) concluded that this relationship is likely due to the common nature of braking and propulsive forces in both CMJ and COD as the ability to utilise both eccentric and concentric muscle contractions is essential to countermovement jump (CMJ) performance (26). As such, measurements of braking and propulsive forces expressed throughout a CMJ will be analysed to find relationships with step characteristics and performance in the repeated 20m-shuttle test.

Theoretically athletes with greater eccentric muscle capabilities will be able to produce a greater amount of impulse which will allow for an increased ability to reduce velocity and momentum. This should subsequently allow for a reduced braking distance, in turn allowing for more acceleration distance. However, this theory must be investigated to outline the physical determinants of repeated 20m shuttle performance and the differences in physical capability between the best and worst performers. Furthermore, the impact that these physical determinants have on step characteristics such as step velocity and braking distance should be discussed in order to inform practitioner's training prescription for improving performance in RCOD.

The aim of this study was to investigate the physical determinants of repeated 20m shuttle performance while exploring the role of step characteristics during the shuttle. A secondary aim was to compare physical characteristics and step characteristics of faster and slower performers as well as least and most fatigued performers and to compare these within gender groups. It is hypothesised that improved performance in the repeated 20m-shuttle test will be associated with increased braking capabilities as characterised by eccentric capacity in the CMJ and increased deceleration work in the 20m-shuttle.

CHAPTER 2: METHODS

Experimental Approach to the Problem. This study used a cross-sectional design where twenty-nine subjects were assessed for repeated 20m-shuttle performance, step characteristics and CMJ variables. This study aimed to determine a) the physical determinants and step characteristics of repeated 20m-shuttle performance; b) differences in physical determinants and step characteristics of faster and slower performers; c) differences in physical determinants and step characteristics of subjects who exhibited less or more fatigue decrement; d) differences in physical determinants and step characteristics of repeated 20m shuttle performance within gender groups.

Subjects. Twenty-nine international field hockey players participated in the study (female, n = 16; mean ± SD: age = 24.6 ± 2.7; mass = 64.63kg ± 4.88) (male, n = 13; mean ± SD: age = 26.2 ± 3.9; mass = 84.7kg ± 7.99). The investigation was approved by the St Mary's University institutional ethics review board, and all subjects were informed of the risks and benefits of participating in the investigation (Appendix A), before signing a consent document to participate in the study (Appendix B). This investigation was conducted according to the principles expressed in the Declaration of Helsinki 2013.

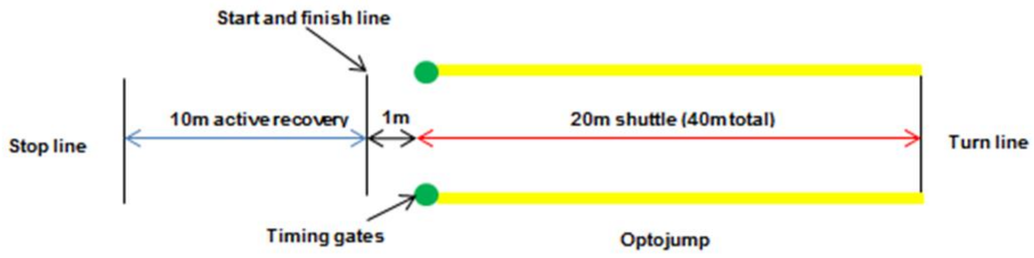
Procedures. Testing took place over a seven-day period with repeated 20m-shuttle performance, and CMJ performance tested on separate days. All athletes had completed both the repeated 20m shuttle test and the CMJ test in previous testing blocks and were therefore deemed to be familiar with the protocols. A standard warm up including five minutes of low-intensity cycling, 5 minutes of dynamic stretching, 5 minutes of dynamic running drills and 1-2 repetitions of the 20m shuttle at >90% intensity were performed to ensure athletes were familiar with the task before completing both repeated 20m-shuttle test and CMJ. All subjects were asked to refrain from strenuous activity for 24 hours before testing.

Repeated 20m Shuttle Test. To assess repeated 20m-shuttle performance subjects performed 8 x 40m (20m: 20m shuttle with active 20m recovery) maximal efforts on a rolling 30-second clock (Figure 1). The duration of the sprint dictated the recovery available within the rolling 30 seconds. The recovery performed was active with the subject required to come to a complete stop before a line 10m from the finish line and return to the start (total 20m) during their recovery period. The subjects started 1m behind the timing gate; their foot was required to touch the line situated at the end of the 20m turning point. The time to perform each shuttle was recorded using photocell timing gates (Witty Timer, Microgate, Bolzano, Italy). To determine the impact of step characteristics throughout each shuttle, step velocity was calculated as

$$step\ velocity = \frac{step\ length}{contact\ time + flight\ time}$$

recorded using Optojump (Optojump Next, Microgate, Bolzano, Italy). This test protocol is in line with the recommendations of Spencer et al. (2004) who suggested, via a time-motion analysis study, that an RSA test, specific to field field hockey, may require as many as six to seven sprints with ≤ 21 seconds between sprints and involve an active recovery. The test has been extended to 8 repetitions to increase fatigue sensitivity.

Figure 1. Repeated 20m shuttle test schematic.



The performance variables of the repeated 20m-shuttle test were total time (TT) (coefficient of variation (CV) = 4.63%), fastest time (FT) (CV = 4.68%), and fatigue percentage (FP) (CV = 39.57%). TT represented the sum of all eight shuttles, FT represented the fastest time for one shuttle, and FP was calculated as

$$FP = [\left(\frac{TT}{8}\right) - FT)/FT]100$$

(42,43,49). Step characteristics measured using Optojump included braking distance (m), entrance maximum velocity (m/s), exit maximum velocity (m/s), entrance 3rd step velocity (m/s), exit 3rd step velocity (m/s), entrance 5th step velocity (m/s), exit 5th step velocity (m/s), braking work (J) and propulsive work (J). Braking distance was measured as the distance of maximum velocity from the turn and is presented as a negative value i.e. 5m from the turn = -5m. Entrance maximum velocity was measured as the subject's maximum velocity during the first 20m of the shuttle. Exit maximum velocity was measured as the subject's maximum velocity during the 2nd 20m of the shuttle. Braking work was calculated as

$$\frac{[(\boldsymbol{BM} \times 1st\ 20m\ maximum\ velocity)^2/2]}{\boldsymbol{braking}\ distance}$$

, propulsive work was calculated as

$$\frac{[(\boldsymbol{BM} \times 2nd\ 20m\ 3rd\ step\ velocity)^2/2]}{3rd\ step\ location}$$

, and entrance 3rd and 5th step velocity were measured as the subject's velocity at their 3rd and 5th step respectively during the 1st 20m of the shuttle. Exit 3rd and 5th step velocity were measured as the subject's velocity at their 3rd and 5th step respectively during the 2nd 20m of the shuttle. All step characteristics are presented as the mean value taken from all eight repetitions.

Countermovement Jump Test. To assess lower body power variables, subjects performed three maximal effort countermovement jumps (CMJ). CMJs started from a stationary position with the subject's feet set approximately shoulder width apart. The subject's hands remained on their hips throughout the whole movement. The force plates were tared before each trial. The subjects paused in a stationary position for 1-2 seconds on the force plate before jumping to allow more reliable measurement. Subjects were instructed to jump as high as possible with their knees and hips remaining fully extended, avoiding tucking or piking. Peak power (W), relative peak power (W/kg), relative mean power absorption, eccentric impulse (Ns) and mean eccentric power (W) were calculated from the highest CMJ trial performed on force plates sampling at 1000Hz (FD4000, Forcedecks NMP Technologies, UK) (CV = 4.3-6.3%) (35).

Statistical Analysis. Statistical analysis was performed using SPSS software version 22 (SPSS, Chicago, Ill, USA). Normality was tested using Kolmogorov-Smirnov[a]. Relationships between shuttle performance, step characteristics, and physical determinants were analysed using Pearson's product-moment correlation and coefficient of determination. Correlations were evaluated using the following scale; small (.10 – .29), moderate (.30 – .49), large (≥.50) (10). Statistical significance of differences between gender groups was calculated using Fisher's z-Test. Comparisons of physical determinants and step characteristics were also made between the best and worst performers for TT and FP, for the whole group (upper and lower 25% of the sample) and within genders (top and bottom five subjects). Independent T-tests and Eta effect sizes were used to assess the magnitude of differences between best and worst performers. Effect sizes were calculated using the formula Eta squared = $t^2 \div (t^2 + (N1 + N2 - 2))$. Effect sizes were interpreted as small ($\geq .01$), moderate ($\geq .06$) and large ($\geq .14$) (10). Stepwise linear regressions were carried out to formulate a regression model, explaining variance in TT. The criterion for significance was set at $p \leq .05$ for all tests.

CHAPTER 3: RESULTS

Means and standard deviations for each tested variable for the whole group and gender groups are provided in Table 1.

Table 1. Cross sectional data reported by gender as mean ± standard deviation.

Variables	Whole Cohort (n = 29)	Male (n = 13)	Female (n = 16)
Total Time (s)	58.76 ± 2.72	56.26 ± 1.42	60.79 ± 1.55
Fastest Time (s)	7.06 ± .33	6.75 ± .12	7.31 ± .20
Fatigue (%)	4 ± 2	4 ± 2	4 ± 1
Average Eccentric Power [W]	484 ± 118	577 ± 98	409 ± 68
Eccentric Impulse [Ns]	-3.45 ± 1.47	-4.27 ±1.25	-2.79 ± 1.33
Peak Power [W]	3714 ± 843	447 ± 625	3097 ± 331
Relative Peak Power [W/kg]	51± 6	55 ± 4	48± 5
Braking Distance (m)	-5.62 ± .97	-5.59 ± .73	-5.64 ± 1.15
Entrance Maximum Velocity (m/s)	7.69 ± .58	8.17 ± .45	7.29 ± .32
Exit Maximum Velocity (m/s)	7.34 ± .50	7.758 ± .39	6.999 ± .28
Braking Work (J)	404.43 ± 123.62	496.08 ± 98.96	329.97 ± 86.61
Propulsive Work (J)	132.49 ± 54.62	168.62 ± 58.26	103.13 ± 27.30
Entrance 3rd Step Velocity (m/s)	5.37 ± .31	5.53 ± .28	5.238 ± .27
Exit 3rd Step Velocity (m/s)	2.77 ± .80	3.23 ± .94	2.40 ± .38
Entrance 5th Step Velocity (m/s)	6.18 ± .36	6.42 ± .23	5.99 ± .33
Exit 5th Step Velocity (m/s)	5.02 ± .49	5.40 ± .49	4.72 ± .17

Stepwise multiple regressions were used to assess the ability of the collected variables to predict repeated 20m shuttle performance. Preliminary analyses were conducted to ensure no violation of the assumptions of normality, linearity, multicollinearity and homoscedasticity for all regressions. An identical regression equation was produced to predict TT for the female group when FP was both included and excluded. A statistically significant regression equation was formulated including relative peak power, entrance maximum velocity, and braking distance. TT, $F (3, 12) = 25.385$, $p \leq .000$, $R^2 = .864$.

$$Female\ Predicted\ TT = 85.652 - (0.156 \times Relative\ Peak\ Power) - (1.967 \times Maximum\ Entrance\ Velocity) + (0.538 \times Braking\ Distance).$$

Relative peak power was entered at stage 1, explaining 71.5% of the variance in TT. After input of maximum entrance velocity at step 2, the total variance of TT explained was 82.2%. After entry of braking distance at step 3, the total variance explained by the model as a whole was 85.7%. All three variables added statistically significantly to the prediction ($p \leq .05$).

For the male group, a statistically significant regression equation was formulated to predict TT when FP was included using FP, relative peak power and exit 5th step velocity, TT, $F (3, 9) = 27.480$, $p \leq .000$, $R^2 = .902$

$$Male\ Predicted\ TT\ (including\ FP) = 65.754 + (80.548 \times FP) - (0.154 \times Relative\ Peak\ Power) - (0.8 \times Exit\ 5th\ Step\ Velocity).$$

FP was entered at stage 1, explaining 53.9% of the variance in TT. After inputting relative peak power at step 2, the total variance of TT explained was 63.8%. After inputting exit 5th step velocity at step 3, the total variance explained by the model as a whole was 65.8%. All three variables added statistically significantly to the prediction ($p \leq .05$).

For the male group, a statistically significant regression equation was formulated to predict TT when FP was not included using entrance maximum velocity, this predicted 72.5% of total variance. TT, $F(1, 11) = 6.999$, $p \leq .05$, $R^2 = .389$. Maximum entrance velocity added statistically significantly to the prediction ($p \leq .05$).

$$Male\ Predicted\ TT\ (excluding\ FP) = 72.482 - (1.984 \times\ Maximum\ Entrance\ Velocity).$$

For both female and male groups a statistically significant regression equation could not be formulated to predict FP using the variables collected.

Stepwise multiple regressions were also used to assess the ability of physical determinants and step characteristics to predict repeated 20m shuttle performance separately. When only physical determinants were included a statistically significant regression equation was formulated to predict TT for the female group using relative peak power, this predicted 71.5% of total variance. TT, $F(1,14) = 26.292$, $p \leq .000$, $R^2 = .653$. Relative peak power added statistically significantly to the prediction ($p \leq .05$).

$$Female\ Predicted\ TT\ \ (physical\ determinants) = 71.470 - (0.222 \times Relative\ Peak\ Power).$$

When only step characteristics were included a statistically significant regression equation was formulated to predict TT for the female group using entrance 3rd step velocity, this predicted 83.4% of total variance. TT, $F(1,14) = 18.634$, $p \leq .001$, $R^2 = .571$. Entrance 3rd step velocity added statistically significantly to the prediction ($p \leq .05$).

$$Female\ Predicted\ TT\ (step\ characteristics) = 83.360 - (4.308 \times Entrance\ 3rd\ Step\ Velocity).$$

For the male group a statistically significant regression equation could not be formulated to predict TT using physical determinants. When only step characteristics were included a statistically significant regression equation was formulated to predict TT for the male group using entrance maximum velocity, this predicted 72.5% of total variance. TT, $F(1,11) = 6.999$, $p \leq .05$, $R^2 = .389$. Entrance maximum velocity added statistically significantly to the prediction ($p \leq .05$).

$$Male\ Predicted\ TT\ (step\ characteristics) = 72.482 - (1.984 \times Entrance\ Maximum\ Velocity).$$

Pearson's correlation coefficients (r) and coefficients of determination (r^2) were calculated for the whole group, r values are presented in Table 2 for all variables. TT showed significant large correlation with variables taken from the CMJ trial. Propulsive variables peak power ($r = -.716$, $r^2 = .512$, $p \leq .01$) and relative peak power ($r = -.718$, $r^2 = .516$, $p \leq .01$) showed large negative correlation, as did the braking variable average eccentric power ($r = -.588$, $r^2 = .346$, $p > .01$), while eccentric impulse showed moderate positive correlation ($r = .453$, $r^2 = .205$. $p \leq .05$).

TT showed the strongest positive correlation with FT ($r = .947$, $r^2 = .897$, $p \leq .01$). Maximum entrance velocity ($r = -.820$, $r^2 = .672$, $p \leq .01$) and exit velocity ($r = -.796$, $r^2 = .634$, $p \leq .01$), entrance ($r = -.672$, $r^2 = .452$, $p \leq .01$) and exit ($r = -.560$, $r^2 = .314$, $p \leq .01$) 3rd step velocity, and entrance ($r = .726$, $r^2 = .527$, $p \leq .01$) and exit ($r = .743$, $r^2 = .552$, $p \leq .01$) 5th step velocity also all showed large positive correlations with TT. Large positive correlations were found between peak power, maximum entrance ($r = .571$, $r^2 = .326$, $\leq .01$) and exit ($r = .573$, $r^2 = .328$, $p \leq .01$) velocity, entrance ($r = .572$, $r^2 = .327$, $p \leq .01$) and exit ($r = .529$, $r^2 = .280$, $p \leq .01$) 3rd step velocity, and entrance ($r = .594$, $r^2 = .210$, $p \leq .01$) and exit ($r = .735$, $r^2 = .540$, $p \leq .01$) 5th step velocity. TT also showed large negative correlation with the ability to perform braking work ($r = -.554$, $r^2 = .307$, $p \leq .01$) and propulsive work ($r = -.604$, $r^2 = .365$, $p \leq .01$). Furthermore, braking work showed large negative correlation with CMJ variables eccentric impulse ($r = -.534$, $r^2 = .285$, $p \leq .01$) and average eccentric power ($r = -.564$, $r^2 = .318$, $p \leq .01$).

Pearson's correlation coefficients (r) and coefficients of determination (r^2) were calculated for the gender groups, female r values are presented in Table 2, and male r values in Table 3. Fisher's z-Test was used to calculate if a significant difference existed between correlation coefficients for each group. Significant difference was found for female athletes ($r = -.808$, $r^2 = .653$, $p = \leq .01$) (Figure 2) compared to male athletes ($r = -.59$) (Figure 3) for TT and relative peak power ($z = 2.81$, $p \leq .01$). Significant difference was found between female ($r = -.573$, $r^2 = .328$, $p = \leq .05$) (Figure 4) and male athletes ($r = .290$, $p = .337$) (Figure 5) for TT and peak power ($z = -2.14$, $p \leq .05$). A significant difference was found for male athletes ($r = -.477$, $p = .126$) (Figure 6) compared to female athletes ($r = .610$, $r^2 = .372$, $p \leq 0.05$) (Figure 7) for TT and braking distance ($z = 2.83$, $p \leq 0.01$). Although not statistically significant based on Fisher's z-Test calculations, there was a notable difference in relationships between TT and FP for male athletes ($r = .718$, $r^2 = .516$, $p \leq 0.01$) and female athletes ($r = .117$, $p = .667$). Furthermore for the male group peak power ($r = .747$, $r^2 = .558$, $p \leq 0.01$), relative peak power ($r = .573$, $r^2 = .328$, $p \leq 0.05$) and exit maximum velocity ($r = .563$, $r^2 = .317$, $p \leq 0.05$) showed moderate to large relationships with FP. Further findings that were notable but not statistically significant include the large negative relationships found for female athletes between TT and entrance 3rd step velocity ($r = -.756$, $r^2 = .345$, $p \leq 0.01$) and entrance 5th step velocity ($r = -.596$, $r^2 = .337$, $p \leq 0.05$), compared to male athletes, entrance 3rd step velocity ($r = -.347$, $p = .246$) and entrance 5th step velocity ($r = -.347$, $p = .246$).

Table 2. Pearson's correlation coefficients between shuttle performance, CMJ variables and shuttle step characteristics.

	FT	TT	FP	Av Ecc Pwr	Ecc Imp	P Pwr	RP Pwr	Brk Dist	Max Ent Vel	Max Ex Vel	Brk Work	Pro Work	Ent3rd Step Vel	Exit 3rd Step Vel	Ent 5th Step Vel	Ex 5th Step Vel
FT																
TT	.947**															
FP	-.187	.140														
Av Ecc Pwr	-.607**	-.588**	.084													
Ecc Imp	.416*	.453*	.094	-.765**												
P Pwr	-.838**	-.716**	.400*	.755**	-.495**											
RP Pwr	-.826**	-.718**	.352	.458*	-.287	.797**										
Brk Dist	.147	.124	-.080	-.055	-.217	-.117	-.241									
Max Ent Vel	-.770**	-.821**	-.140	.445*	-.393*	.571**	.481**	.269								
Max Ex Vel	-.729**	-.796**	-.192	.539**	-.382*	.573**	.440*	-.146	.783**							
Brk Work	-.547**	-.554**	-.007	.488**	-.534**	.564**	.288	.621**	.800**	.489**						
Pro Work	-.619**	-.604**	.067	.278	-.223	.571**	.500**	-.017	.542**	.534**	.407*					
Ent 3^{rd} Step Vel	-.692**	-.672**	.080	.460*	-.278	.572**	.692**	-.369*	.373*	.499**	.133	.268				
Ex 3^{rd} Step Vel	-.573**	-.560**	.055	.203	-.154	.529**	.461*	-.024	.526**	.510**	.368*	.940**	.309			
Ent 5^{th} Step Vel	-.740**	-.726**	.064	.462*	-.327	.594**	.670**	-.295	.497**	.600**	.215	.410*	.888**	.420*		
Ex 5^{th} Step Vel	-.747**	-.743**	.033	.487**	-.377*	.735**	.580**	-.086	.616**	.605**	.505**	.704**	.561**	.805**	.555**	

Note. FT = Fastest Time, TT = Total Time, FP = Fatigue Percentage, Av Ecc Pwr = Average Eccentric Power, Ecc Imp = Eccentric Impulse, P Pwr = Peak Power, RP Pwr = Relative Peak Power, Brk Dist = Braking Distance, Max Ent Vel = Maximum Entrance Velocity, Max Ex Vel = Maximum Exit Velocity, Brk Work = Braking Work, Pro Work = Propulsive Work, Ent 3^{r}Step Vel = Entrance 3^{rd} Step Velocity, Ex 3^{rd} Step Vel = Exit 3^{rd} Step Velocity, Ent 5^{th} Step Vel = Entrance 5^{th} Step Velocity, Ex 5^{th} Step Vel = Exit 5^{th} Step Velocity, r = Pearson's Correlation Coefficient, *$p \leq .05$, **$p \leq .01$, N = 29 for all analyses

Table 3. Pearson's correlation coefficients between shuttle performance, CMJ variables and shuttle step characteristics in elite female field hockey players

	FT	TT	FP	Av Ecc Pwr	Ecc Imp	P Pwr	RP Pwr	Brk Dist	Max Ent Vel	Max Ex Vel	Brk Work	Pro Work	Ent3rd Step Vel	Exit 3rd Step Vel	Ent 5th Step Vel	Ex 5th Step Vel
FT																
TT	.862**															
FP	-.402	.117														
Av Ecc Pwr	.01	-.085	-.167													
Ecc Imp	-.16	-.034	.245	-.751**												
P Pwr	-.696**	-.573*	.327	.305	-.084											
RP Pwr	-.857**	-.808**	.215	.083	.097	.761**										
Brk Dist	.524*	.610*	.076	-.09	-.231	-.447	-.486									
Max Ent Vel	-.326	-.401	-.088	-.197	.175	-.048	.113	.163								
Max Ex Vel	-.421	-.555*	-.178	.093	.262	.29	.355	-.586*	.342							
Brk Work	.364	.431	.067	-.051	-.218	-.277	-.491	.868**	.397	-.407						
Pro Work	.107	.098	-.029	.124	.046	.022	-.051	-.193	-.213	.024	-.153					
Ent 3rd Step Vel	-.736**	-.756**	.072	.071	.168	.549*	.741**	-.603*	.175	.617*	-.586*	-.069				
Ex 3rd Step Vel	.063	.114	.078	-.03	.206	.075	-.036	-.29	-.164	.082	-.239	.866**	-.015			
Ent 5th Step Vel	-.560*	-.596*	.019	.055	.13	.329	.522*	-.475	.233	.526*	-.509*	.01	.871**	.127		
Ex 5th Step Vel	-.233	-.298	-.089	-.069	-.002	.291	.212	-.614*	-.182	.205	-.503*	-.162	.195	.107	.134	

Note. FT = Fastest Time, TT = Total Time, FP = Fatigue Percentage, Av Ecc Pwr = Average Eccentric Power, Ecc Imp = Eccentric Impulse, P Pwr = Peak Power, RP Pwr = Relative Peak Power, Brk Dist = Braking Distance, Max Ent Vel = Maximum Entrance Velocity, Max Ex Vel = Maximum Exit Velocity, Brk Work = Braking Work, Pro Work = Propulsive Work, Ent 3rd Step Vel = Entrance 3rd Step Velocity, Ex 3rd Step Vel = Exit 3rd Step Velocity, Ent 5th Step Vel = Entrance 5th Step Velocity, Ex 5th Step Vel = Exit 5th Step Velocity, $^{*}p \leq .05$, $^{**}p \leq .01$ (two tailed), N = 16 for all analyses.

Table 4. Pearson's correlation coefficients between shuttle performance, CMJ variables and shuttle step characteristics in elite male field hockey players.

	FT	TT	FP	Av Ecc Pwr	Ecc Imp	P Pwr	RP Pwr	Brk Dist	Max Ent Vel	Max Ex Vel	Brk Work	Pro Work	Ent3rd Step Vel	Exit 3rd Step Vel	Ent 5th Step Vel	Ex 5th Step Vel
FT																
TT	.735**															
FP	.057	.718**														
Av Ecc Pwr	.098	.184	.173													
Ecc Imp	.182	.178	.07	-.617*												
P Pwr	-.314	.29	.747**	.464	-.217											
RP Pwr	-.643*	-.059	.573*	.05	-.107	.720**										
Brk Dist	-.295	-.447	-.353	-.15	-.259	-.114	.059									
Max Ent Vel	-.411	-.624*	-.498	-.277	-.171	-.241	.009	.782**								
Max Ex Vel	.036	-.355	-.563*	-.091	-.224	-.363	-.381	.151	.557*							
Brk Work	-.357	-.406	-.233	.032	-.392	.172	.195	.838**	.748**	.205						
Pro Work	-.673*	-.44	.041	-.471	.194	.191	.443	.084	.294	.184	.057					
Ent 3^{rd} Step Vel	-.512	-.347	.019	.304	-.326	.274	.366	-.146	-.117	-.067	.018	-.01				
Ex 3^{rd} Step Vel	-.697**	-.496	-.017	-.41	.159	.224	.414	.133	.366	.241	.125	.932**	.134			
Ent 5^{th} Step Vel	-.503	-.347	.009	.053	-.332	.157	.434	-.152	-.136	-.004	-.082	.135	.879**	.217		
Ex 5^{th} Step Vel	-.712**	-.513	-.026	-.042	-.047	.405	.398	.101	.274	.133	.263	.623*	.492	.827**	.379	

Note. FT = Fastest Time, TT = Total Time, FP = Fatigue Percentage, Av Ecc Pwr = Average Eccentric Power, Ecc Imp = Eccentric Impulse, P Pwr = Peak Power, RP Pwr = Relative Peak Power, Brk Dist = Braking Distance, Max Ent Vel = Maximum Entrance Velocity, Max Ex Vel = Maximum Exit Velocity, Brk Work = Braking Work, Pro Work = Propulsive Work, Ent 3^{rd} Step Vel = Entrance 3^{rd} Step Velocity, Ex 3^{rd} Step Vel = Exit 3^{rd} Step Velocity, Ent 5^{th} Step Vel = Entrance 5^{th} Step Velocity, Ex 5^{th} Step Vel = Exit 5^{th} Step Velocity, $*p \leq .05$, $**p \leq .01$, (two-tailed), N = 13 for all analyses.

Figure 2. Scatter plot showing the correlation between relative peak power and total time in a repeated 20m shuttle test for elite female field hockey players.

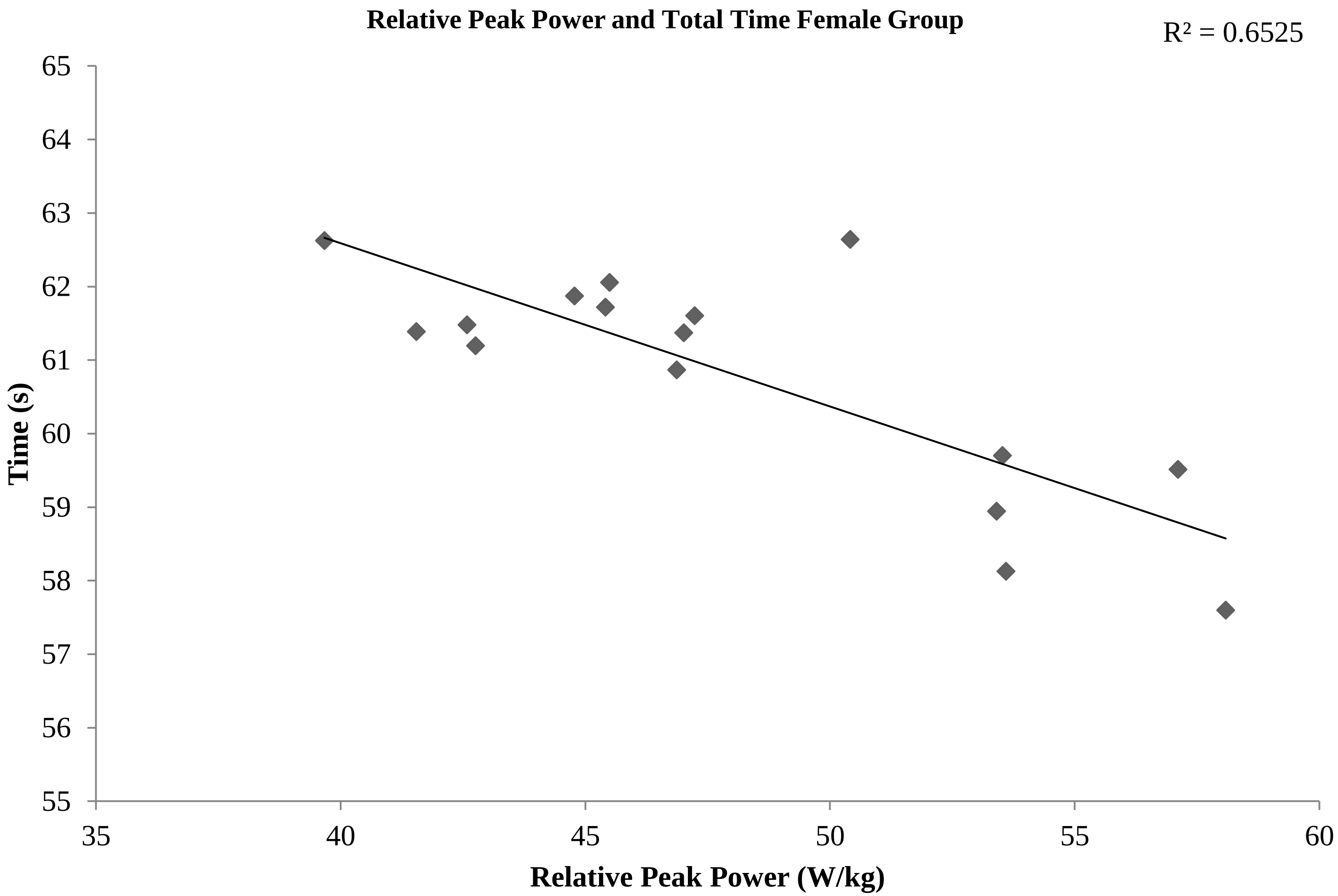


Figure 3. Scatter plot showing the correlation between relative peak power and total time in a repeated 20m shuttle test for elite male field hockey players.

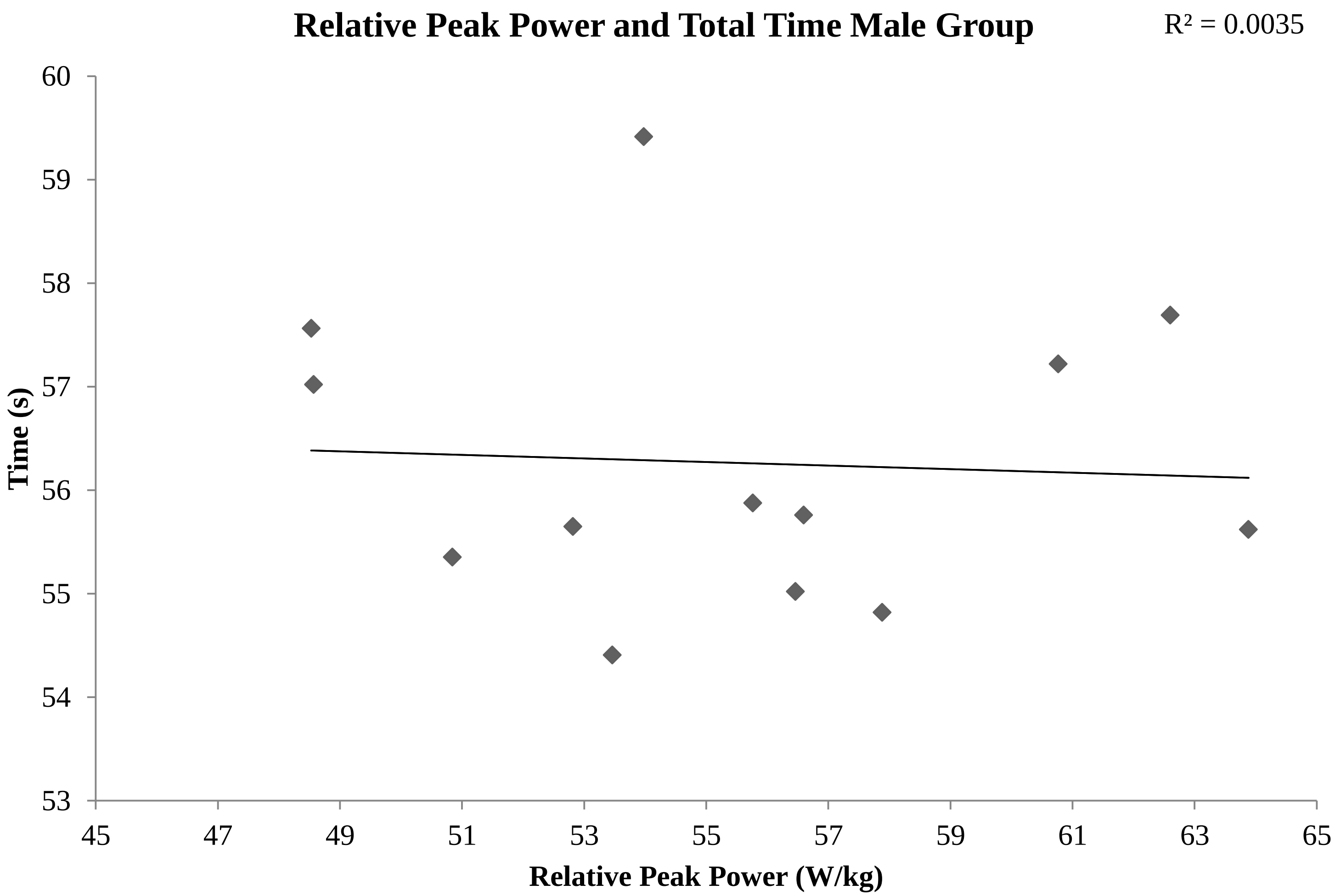


Figure 4. Scatter plot showing the correlation between peak power and total time in a repeated 20m shuttle test for elite female field hockey players.

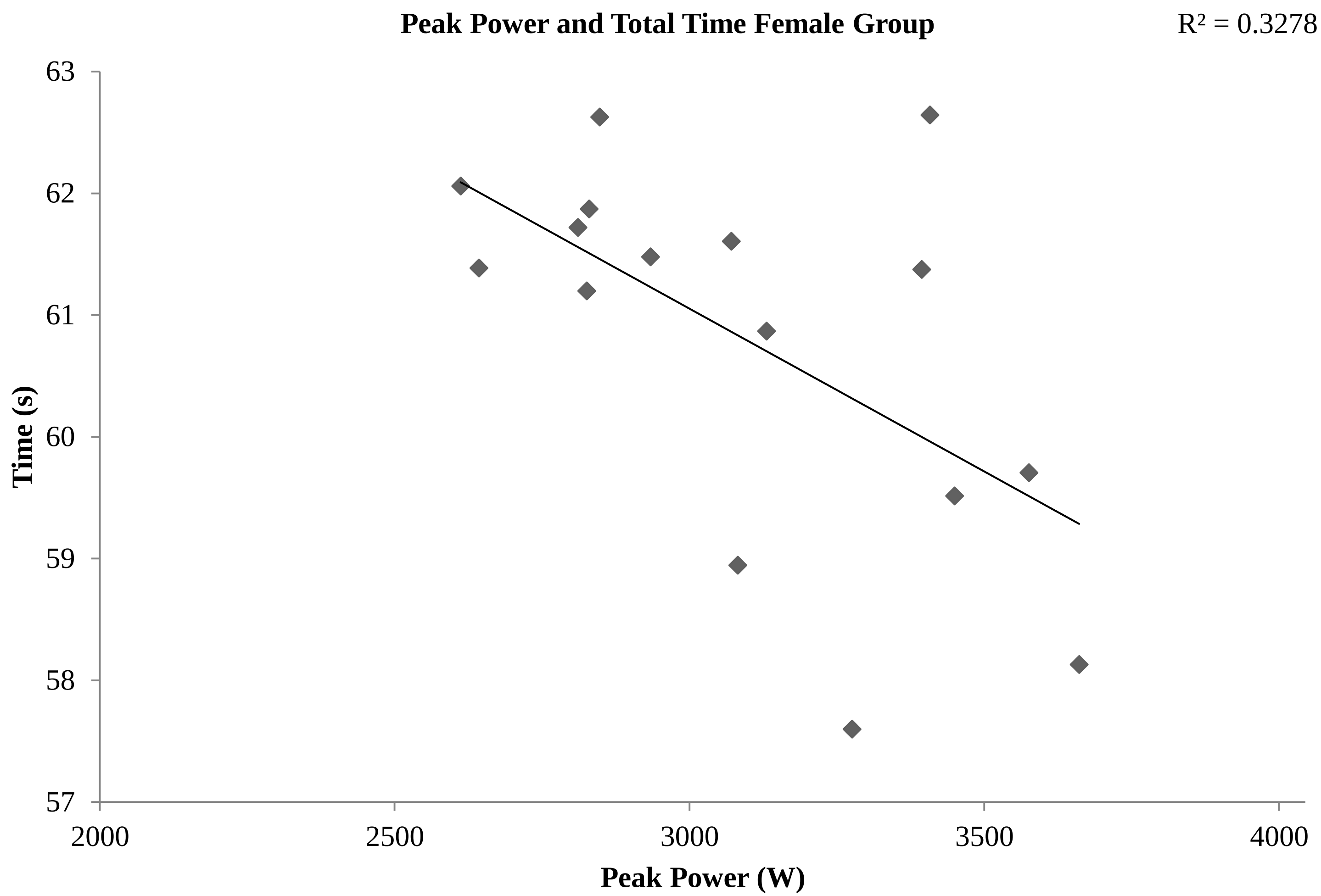


Figure 5. Scatter plot showing the correlation between peak power and total time in a repeated 20m shuttle test for elite male field hockey players.

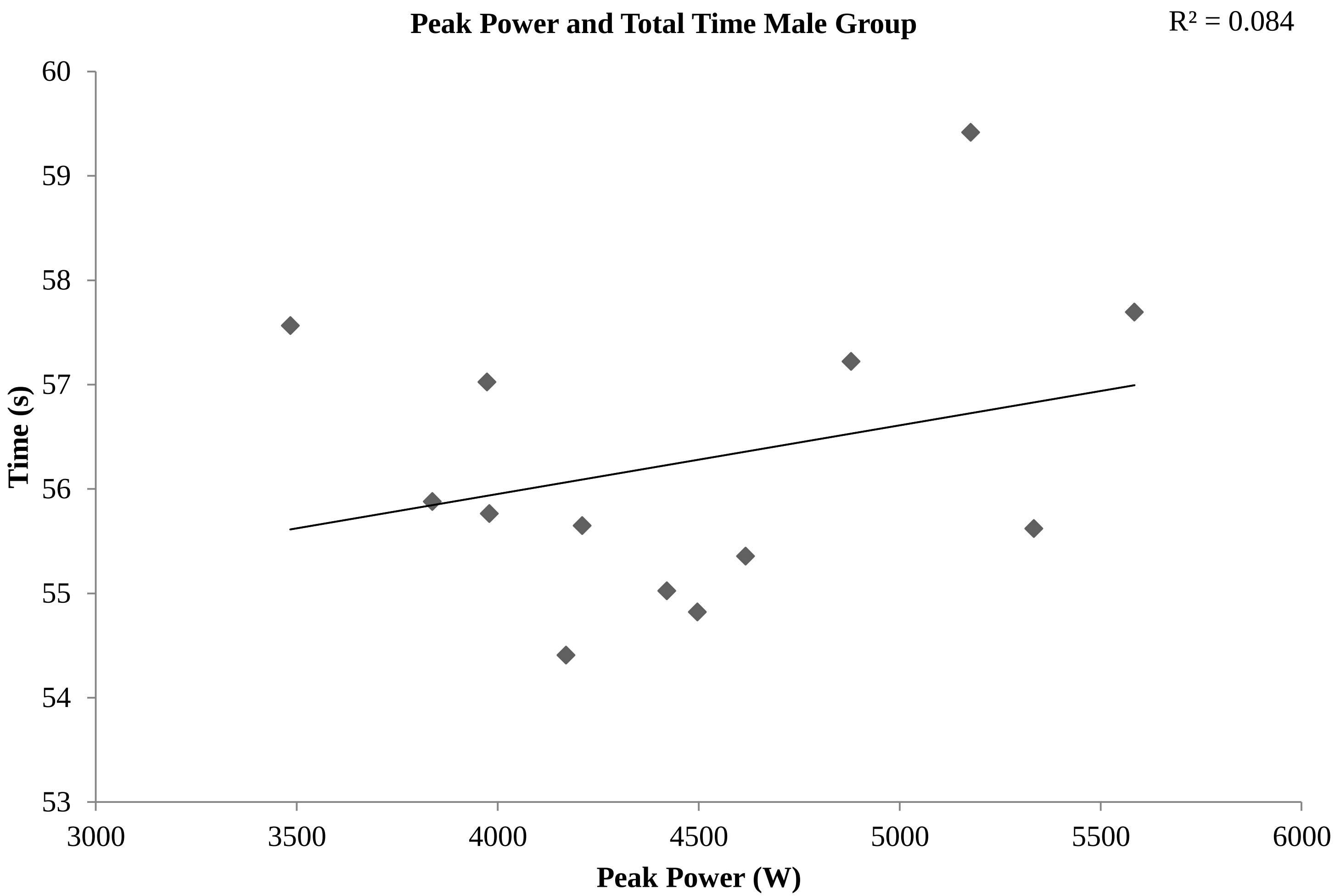


Figure 6. Scatter plot showing the correlation between braking distance and total time in a repeated 20m shuttle test for elite male field hockey players.

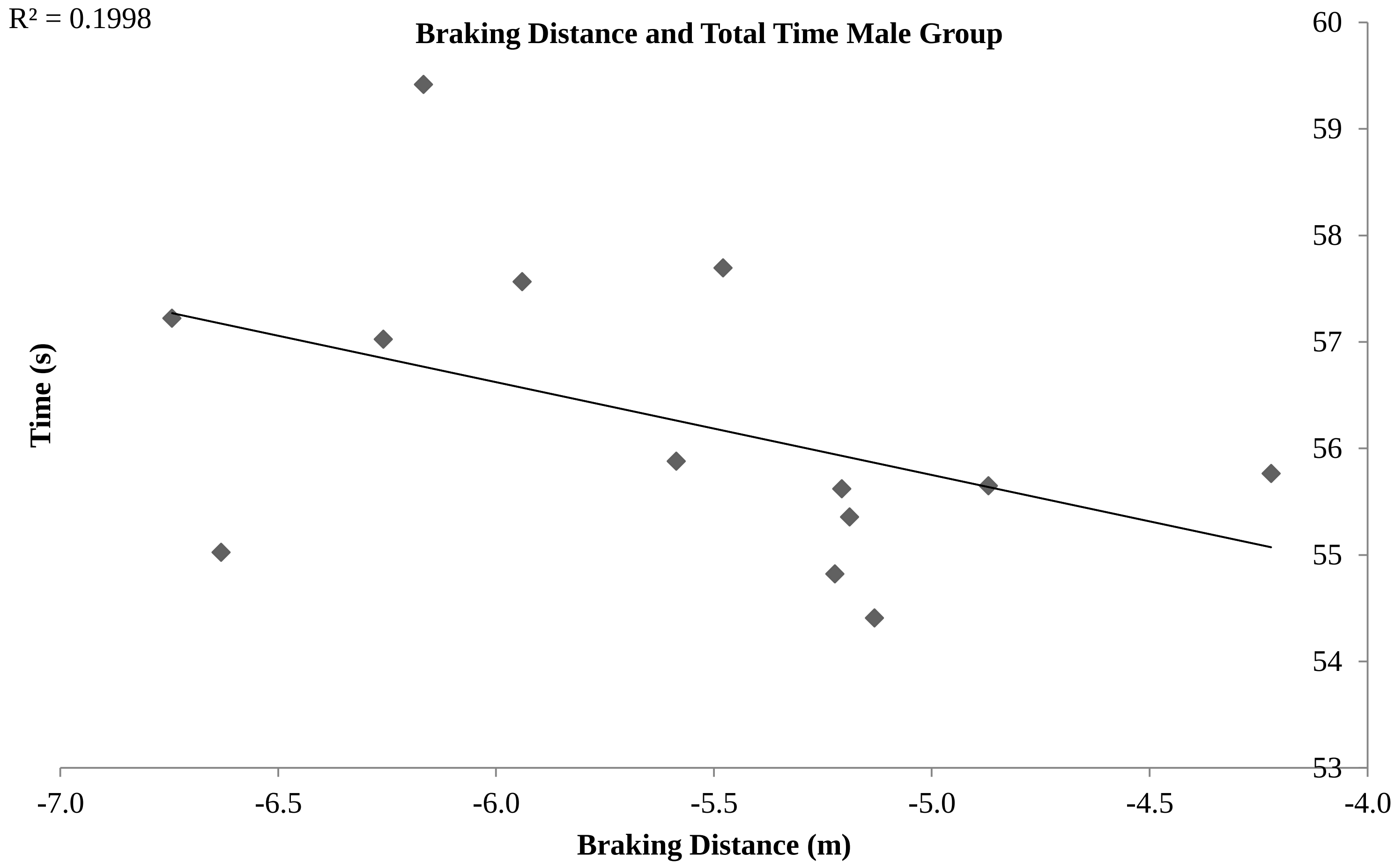


Figure 7. Scatter plot showing the correlation between braking distance and total time in a repeated 20m shuttle test for elite male field hockey players.

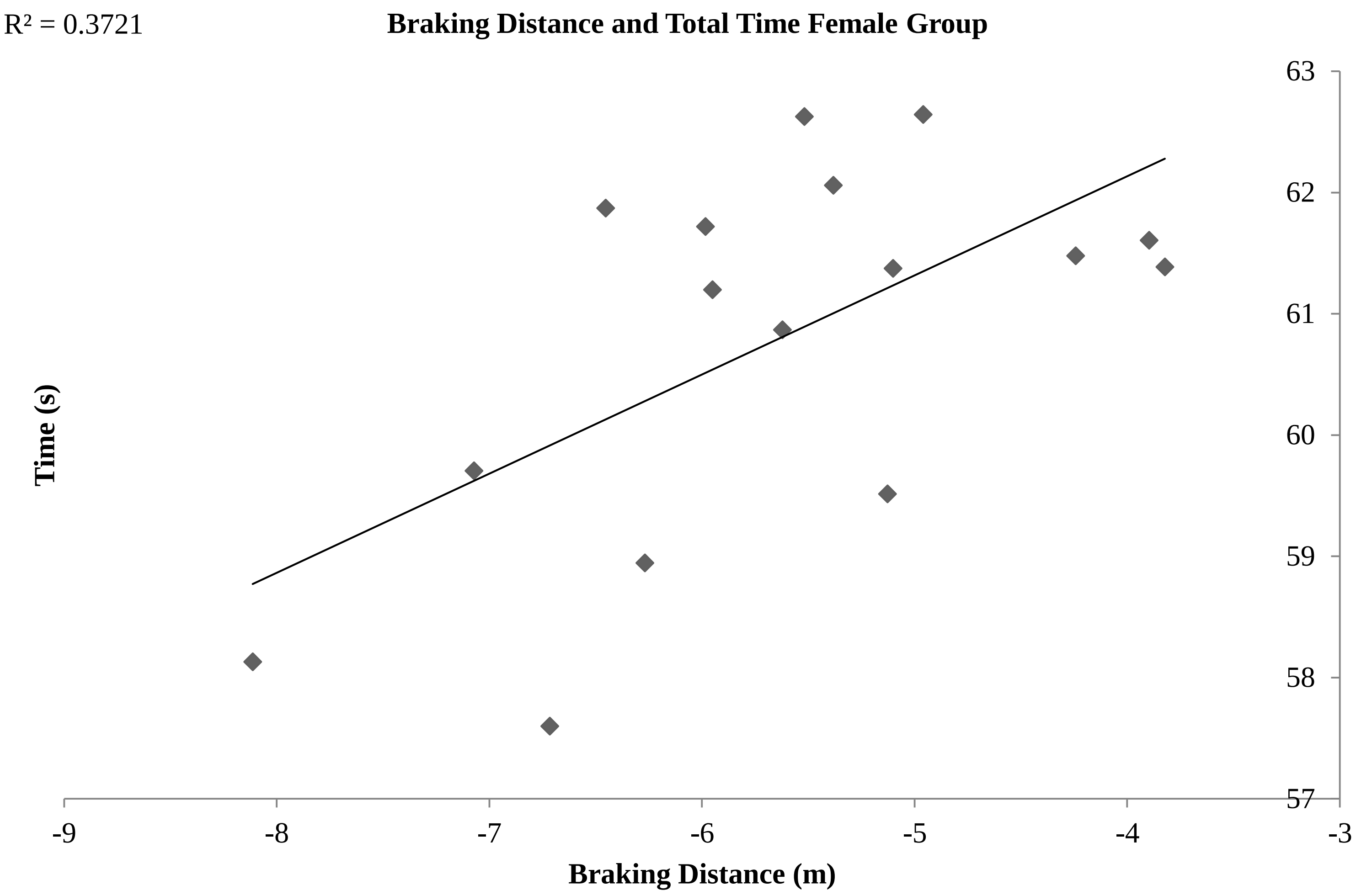
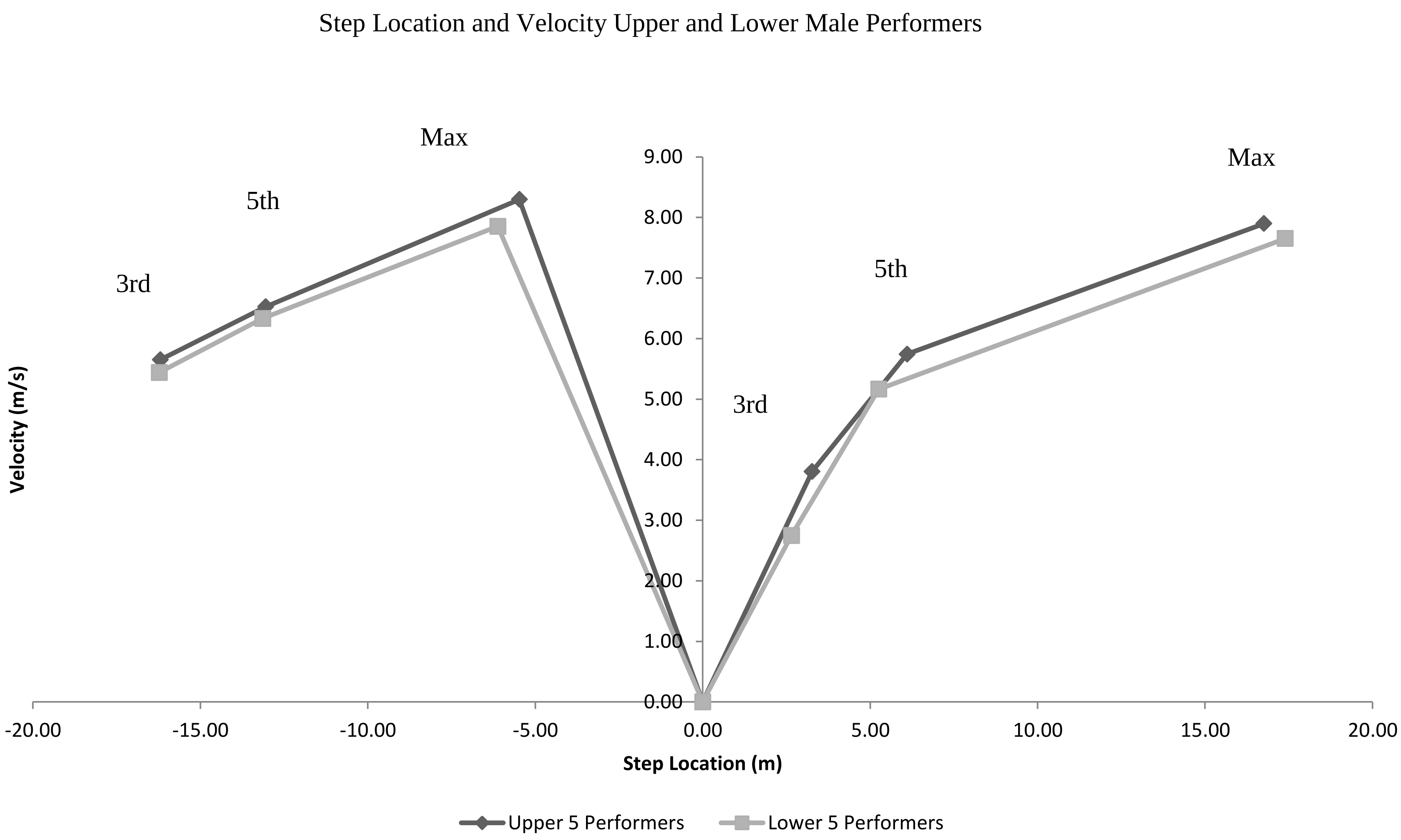
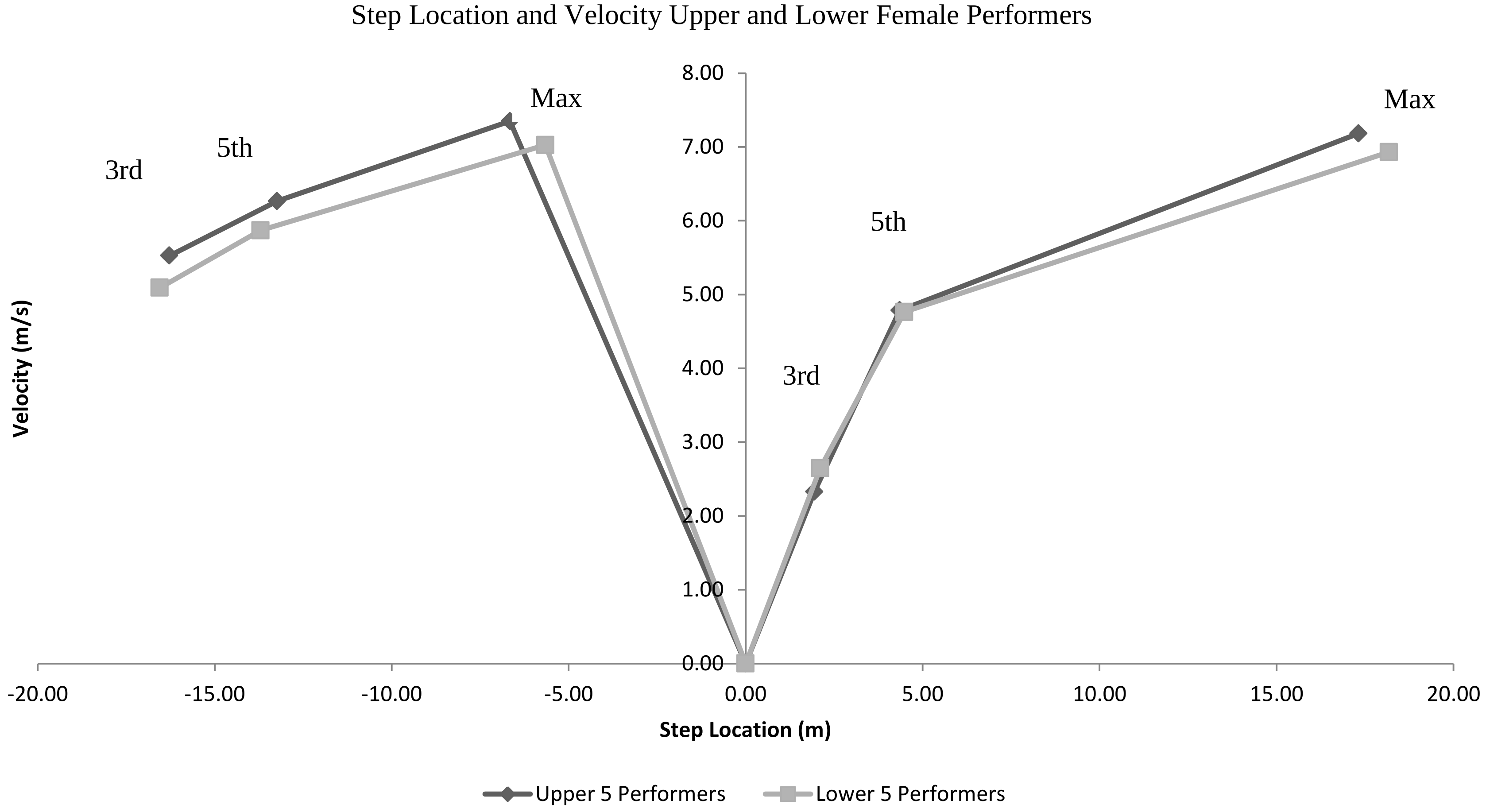


Figure 8. Mean third step, fifth step and maximum step velocity and location for upper and lower 5 male performers for total time in a repeated 20m shuttle test.



Note. 3rd = third step, 5th = fifth step, Max = maximum velocity.

Figure 9. Mean third step, fifth step and maximum step velocity and location for upper and lower 5 female performers for total time in a repeated 20m shuttle test.



Note. 3rd = third step, 5th = fifth step, Max = maximum velocity

Independent T-tests were performed comparing the upper ($n = 5$) performers and lower ($n = 5$) performers based on TT for male (figure 8) and female group (figure 9) . In the female group significant difference was shown for FT ($p \leq .001$, ES = .831), peak power ($p \leq .05$, ES = .528), relative peak power ($p \leq .001$, ES = .760), entrance 3rd step velocity ($p \leq .01$, ES = .70) and entrance 5th step velocity ($p \leq .05$, ES = .452). In the male group significant difference was shown for FT ($p \leq .05$, ES = .546) and exit 5th step velocity ($p \leq .05$, ES = .412). Independent T-tests showed no differences in physical determinants or step characteristics for the upper and lower five performers in the female group when ranked for FP. However, the male group showed significant differences between upper and lower five performers for maximum entrance ($p = .009$, ES = .591) and exit ($p = .041$, ES = .426) velocity, braking work ($p = .029$, ES = .470) and braking distance ($p = .026$, ES = .482).

CHAPTER 4: DISCUSSION

The aim of this study was to investigate the physical determinants and step characteristics of repeated 20m shuttle performance. This study is the first to investigate both the physical determinants and step characteristics of repeated 20m shuttles in a sample of elite male and female performers. The main findings from the study are that key differences exist between physical determinants and step characteristics in faster and slower performers across the whole cohort and also between male and female athletes. Faster athletes demonstrated greater entrance and exit maximum velocities, greater ability to perform both braking and propulsive work, higher power production capabilities and higher eccentric capabilities in the CMJ. Furthermore, results suggest that the abilities to accelerate more rapidly and brake later into the turn play an important role in determining performance in a repeated 20m shuttle test. Acceleration capabilities have been shown to be a stronger determinant of female performance, while the ability to brake later and perform greater amounts of braking work has shown to be a stronger determinant for male athletes. Variables taken from the CMJ test suggest that relative peak power production and eccentric power production capabilities also determine repeated 20m shuttle performance.

The present study found that the main step characteristic determinant of repeated 20m shuttle performance was entrance maximum velocity for the male group, explaining 72.5% of the variance, and entrance 3td step velocity for the female group, explaining 83.4% of variance in TT. Higher acceleration capability is advantageous as athletes are able to spend an increased amount of time at higher velocities. These findings show that the ability to reach high velocities quickly results in improved performance. TT and all velocity measures, 3rd step, 5th step and maximum velocity both entering and exiting the turn, all show large positive relationships, furthermore, the strongest relationship was found between TT and FT. This is in agreement with the hypotheses of the present study; with corroborative studies demonstrating similar findings surrounding relationships between straight line sprint ability and COD performance (7,11,30,33,52,57). As such it is clear that acceleration ability is a significant factor in determining repeated 20m shuttle ability. Therefore practitioners and coaches should aim to increase an athlete’s velocity traveling into and out of a turn.

Previous research has shown that increased lower body power production results in improved straight-line sprint ability (37). It is unsurprising then, given the above findings, that of the variables collected from the CMJ test relative peak power explained 71.4% of performance for the female group. Furthermore, relative peak power showed either moderate or large relationships with all velocity measures, most notably entrance 3rd step ($r = .692$, $r^2 = .749$, $p \leq .01$) and 5th step ($r = .670$, $r^2 = .449$, $p \leq .01$) velocity for the whole cohort. A significant difference was also found between upper and lower female performer’s power production capabilities using an independent T-test. These findings support previous research stating that relative power capability is a predictor of 10m sprint performance (36). As is clear the ability to reach higher velocities more rapidly is an important determinant of an athlete’s ability to perform well in a repeated 20m shuttle test. Furthermore, a large relationship exists between TT, entrance 3rd step velocity and relative peak power. As such practitioners and coaches should consider training prescriptions that aim to increase power to weight ratio and total lower body power production to improve acceleration capabilities and subsequently RCOD ability.

All variables measured during the CMJ test showed moderate or large relationships with TT for the whole cohort. These relationships found for CMJ variables indicate that CMJ performance is a predictor of repeated 20m shuttle performance. This supports the findings of Castillo-Rodriguez et al. (2012) which showed bilateral CMJ performance to have a strong relationship with COD, particularly when the turn was as large as 180°. It is suggested that this is due to the braking and propulsive forces exhibited in both actions requiring similar eccentric and concentric muscle actions. The present study found a large relationship exists between braking work and TT for the whole cohort ($r = .554$; $.307$, $p \leq .01$), while moderate relationship exists between average eccentric power and braking work ($r = .488$; $r^2 = .238$, $p \leq .01$). This is in agreement with the hypotheses of the present study; with corroborative review studies demonstrating that the ability to decelerate more quickly is advantageous in many field and court sports (23). As such, practitioners and coaches should prescribe technical training to reduce braking distance, this could be achieved through technical improvements and, as the present findings suggest, increasing lower body eccentric power production (23). This indicates that improved eccentric qualities, as identified by the CMJ, may enable higher amounts of braking work to be performed throughout a repeated 20m shuttle test. This could enable an athlete to reduce the amount of time in which they perform braking work, allowing greater amounts of time spent either accelerating or maintaining higher velocities.

Comparisons show that significant differences occur in the step characteristics of upper and lower male and female performers. In the female group, the negative relationships between entrance 3rd and 5th step velocity and TT are significantly greater than those in the male group. It is not surprising then, given previous findings, that relative peak power and peak power also show significantly larger relationships with TT than in the male group. In the female group, a large positive relationship exists between braking distance and TT, showing that faster female athletes brake earlier, (Figure 7.). It is possible that a shorter braking distance is sacrificed due to the importance of reaching higher velocities entering the turn. These findings are notably different to that of the male group; while not statistically significant, the relationship between braking distance and TT is negative (Figure 7.). This suggests that male athletes with a lower TT brake later, allowing for increased time spent at higher velocities. These findings warrant further investigation in to the differing strategies employed by male and female athletes.

FP was also found to be a major determinant of male group TT when included in the regression analysis, explaining 53.9% of variance. When ranked by FP male group, upper-level performers demonstrated the ability to brake later entering the turn and therefore perform higher amounts of braking work when compared with lower level performers in the group. This may suggest that the ability to resist fatigue plays a role in enabling these better performers to brake later prior to the turn, allowing for greater time and distance covered at higher velocities. However, a lack of significant difference in the whole cohort and female group suggests that FP may be dependent on other characteristics not investigated in the present study. Previous research suggests that physiological determinants play a large role in repeated shuttle performance, showing higher heart rates, blood lactate levels, lower limb EMG activation and rates of perceived exertion (14,20). The lack of findings for the whole cohort and the female group indicate that further research should be targeted towards the investigation of physiological determinants of repeated shuttle performance. The findings for the male group suggest that these investigations should target developing understanding around the role of deceleration capability and fatigue.

A significant limitation of the study may lie in the accuracy of measurements used to calculate braking distance. Optojump has been found to be an accurate measure of maximal velocity as a product of stride length and frequency. However, this accuracy is reduced during deceleration (1,6,48). Due to the lack of accuracy found for deceleration measurements taken using Optojump a more discrete measurement of braking distance could not be taken. This resulted in a less than ideal calculation being used, which does not take in to account the rate of deceleration that follows the point of maximum velocity entering the turn, defined in this study as braking distance.

However, the relationship between eccentric physical determinants and the ability to perform high amounts of braking work suggest that braking distance may prove to be significant in further investigation as braking distance is included in the calculation of braking work. In future investigations, the use of a more discrete measurement of deceleration will provide further insight into the role of deceleration in repeated shuttle performance.

CHAPTER 5: PRACTICAL APPLICATIONS

In light of the physical determinants that were associated with faster repeated 20m shuttle performance, practitioners are encouraged to develop their athlete's lower limb power production capabilities, both concentric and eccentric. This is due to the importance of step characteristics including acceleration capability and the ability to perform high amounts of braking work for improved repeated 20m shuttle performance. For all athletes, the development of propulsive capabilities is important in order to improve acceleration and relative peak power which predict female performance and maximum entrance velocity which predicts male performance in a repeated 20m shuttle test.

REFERENCE LIST

1. Ammann, R, Taube, W, and Wyss, T. Accuracy of PARTwear Inertial Sensor and Optojump Optical Measurement System for Measuring Ground Contact Time During Running: *Journal of Strength and Conditioning Research* 30: 2057–2063, 2016.

2. Aziz, AR, Chia, M, and Teh, KC. The relationship between maximal oxygen uptake and repeated sprint performance indices in field field hockey and soccer players. *Journal of Sports Medicine and Physical Fitness* 40: 195, 2000.

3. Bishop, D, Spencer, M, Duffield, R, and Lawrence, S. The validity of a repeated sprint ability test. *Journal of Science and Medicine in Sport* 4: 19–29, 2001.

4. Bloomfield, J, Polman, R, and O'Donoghue, P. Physical demands of different positions in FA Premier League soccer. *J Sports Sci Med* 6: 63–70, 2007.

5. Bravo, D, Impellizzeri, F, Rampinini, E, Castagna, C, Bishop, D, and Wisloff, U. Sprint vs. Interval Training in Football. *International Journal of Sports Medicine* 29: 668–674, 2008.

6. Bridgman, CF. Biomechanical evaluation of distance running during training and competition. University of Salford, 2015 [cited 2017 May 20].Available from: http://usir.salford.ac.uk/34545/

7. Brughelli, M, Cronin, J, Levin, G, and Chaouachi, A. Understanding change of direction ability in sport. *Sports medicine* 38: 1045–1063, 2008.

8. Buchheit, M, Mendez-Villanueva, A, Delhomel, G, Brughelli, M, and Ahmaidi, S. Improving repeated sprint ability in young elite soccer players: repeated shuttle sprints vs. explosive strength training. *The Journal of Strength & Conditioning Research* 24: 2715–2722, 2010.

9. Castillo-Rodríguez, A, Fernández-García, JC, Chinchilla-Minguet, JL, and Carnero, EÁ. Relationship between muscular strength and sprints with changes of direction. *The Journal of Strength & Conditioning Research* 26: 725–732, 2012.

10. Cohen, J. Statistical Power Analysis for the Behavioural Sciences. 2nd ed. United States of America: Lawrence Erlbaum Associates, 1988.

11. Condello, G, Schultz, K, and Tessitore, A. Assessment of sprint and change-of-direction performance in college football players. *International Journal of Sports Physiology and Performance* 8: 211–212, 2013.

12. Cronin, JB and Hansen, KT. Strength and power predictors of sports speed. *The Journal of Strength & Conditioning Research* 19: 349–357, 2005.

13. Dellal, A, Keller, D, Carling, C, Chaouachi, A, Wong, DP, and Chamari, K. Physiologic effects of directional changes in intermittent exercise in soccer players. *The Journal of Strength & Conditioning Research* 24: 3219–3226, 2010.

14. Dellal, A and Wong, DP. Repeated sprint and change-of-direction abilities in soccer players: effects of age group. *The Journal of Strength & Conditioning Research* 27: 2504–2508, 2013.

15. Dos'Santos, T, Thomas, C, Jones, PA, and Comfort, P. Mechanical Determinants of Faster Change of Direction Speed Performance in Male Athletes: *Journal of Strength and Conditioning Research* 31: 696–705, 2017.

16. Fessi, M, Makni, E, Jemni, M, Elloumi, M, Padulo, J, Nabli, M, et al. Reliability and criterion-related validity of a new repeated agility test. *Biology of Sport* 33: 159–164, 2016.

17. Gharbi, Z, Dardouri, W, Haj-Sassi, R, Castagna, C, Chamari, K, and Souissi, N. Effect of the number of sprint repetitions on the variation of blood lactate concentration in repeated sprint repetitions. *Biology of Sport* 31: 151–156, 2014.

18. Gil, S, Ruiz, F, Irazusta, A, Gil, J, and Irazusta, J. Selection of young soccer players in terms of anthropometric and physiological factors. *Journal of Sports Medicine and Physical Fitness* 47: 25–32, 2007.

19. Glaister, M, Howatson, G, Pattison, JR, and McInnes, G. The reliability and validity of fatigue measures during multiple-sprint work: an issue revisited. *The Journal of Strength & Conditioning Research* 22: 1597–1601, 2008.

20. Hader, K, Mendez-Villanueva, A, Ahmaidi, S, Williams, BK, and Buchheit, M. Changes of direction during high-intensity intermittent runs: neuromuscular and metabolic responses. *BMC sports science, medicine and rehabilitation* 6: 2, 2014.

21. Haj-Sassi, R, Dardouri, W, Gharbi, Z, Chaouachi, A, Mansour, H, Rabhi, A, et al. Reliability and validity of a new repeated agility test as a measure of anaerobic and explosive power. *The Journal of Strength & Conditioning Research* 25: 472–480, 2011.

22. Havens, KL and Sigward, SM. Cutting Mechanics: Relation to Performance and Anterior Cruciate Ligament Injury Risk. *Medicine & Science in Sports & Exercise* 47: 818–824, 2015.

23. Hewit, J, Cronin, J, Button, C, and Hume, P. Understanding deceleration in sport. *Strength & Conditioning Journal* 33: 47–52, 2011.

24. Hoffman, JR, Ratamess, NA, Klatt, M, Faigenbaum, AD, and Kang, J. Do Bilateral Power Deficits Influence Direction-Specific Movement Patterns? *Research in Sports Medicine* 15: 125–132, 2007.

25. Hopkins, WG. Measures of reliability in sports medicine and science. *Sports medicine* 30: 1–15, 2000.

26. Hsieh, CT and Cheng, L. Kinematic Factors in Countermovement Jump for Female Volleyball Players with Different Skill Levels. *International Journal of Sports Science* 6: 6–10, 2016.

27. James, K. A discussion of the physical determinants of ground based change of direction: a brief review. , 2013.

28. Jindrich, DL, Besier, TF, and Lloyd, DG. A hypothesis for the function of braking forces during running turns. *Journal of Biomechanics* 39: 1611–1620, 2006.

29. Jones, P, Bampouras, T, and Marrin, K. An investigation into the physical determinants of change of direction speed. *Journal of Sports Medicine and Physical Fitness* 49: 97–104, 2009.

30. Koklu, Y, Alemdaroglu, U, Ozkan, A, Koz, M, and Ersoz, G. The relationship between sprint ability, agility and vertical jump performance in young soccer players. *Science & Sports* 30: 1–5, 2015.

31. Kovacs, MS. Applied physiology of tennis performance. *British Journal of Sports Medicine* 40: 381–386, 2006.

32. Lakomy, J and Haydon, DT. The effects of enforced, rapid deceleration on performance in a multiple sprint test. *The Journal of Strength & Conditioning Research* 18: 579–583, 2004.

33. Little, T and Williams, AG. Specificity of acceleration, maximum speed, and agility in professional soccer players. *The Journal of Strength & Conditioning Research* 19: 76–78, 2005.

34. Mann, JB, Ivey, PA, Mayhew, JL, Schumacher, RM, and Brechue, WF. Relationship Between Agility Tests and Short Sprints: Reliability and Smallest Worthwhile Difference in National Collegiate Athletic Association Division-I Football Players. *The Journal of Strength & Conditioning Research* 30: 893–900, 2016.

35. Markovic, G, Dizdar, D, Jukic, I, and Cardinale, M. Reliability and factorial validity of squat and countermovement jump tests. *The Journal of Strength & Conditioning Research* 18: 551–555, 2004.

36. Maulder, PS, Bradshaw, EJ, and Keogh, J. Jump kinetic determinants of sprint acceleration performance from starting blocks in male sprinters. *Journal of Sports Science and Medicine* 5: 359–366, 2006.

37. McFarland, I, Dawes, J, Elder, C, and Lockie, R. Relationship of Two Vertical Jumping Tests to Sprint and Change of Direction Speed among Male and Female Collegiate Soccer Players. *Sports* 4: 11, 2016.

38. McGee, KJ and Burkett, LN. The National Football League Combine: A Reliable Predictor of Draft Status? *The Journal of Strength & Conditioning Research* 17: 6–11, 2003.

39. Meylan, C, McMaster, T, Cronin, J, Mohammad, NI, Rogers, C, and others. Single-leg lateral, horizontal, and vertical jump assessment: reliability, interrelationships, and ability to predict sprint and change-of-direction performance. *The Journal of Strength & Conditioning Research* 23: 1140–1147, 2009.

40. Mizuguchi, S, Gray, H, Calabrese, L, Haff, G, Sands, W, Ramsey, M, et al. Repeated change-of-direction test for collegiate male soccer players. *Journal of Sports Medicine and Physical Fitness* 54: 417–423, 2014.

41. Montgomery, PG, Pyne, DB, and Minahan, CL. The physical and physiological demands of basketball training and competition. *International Journal of Sports Physiology and Performance* 5: 75–86, 2010.

42. Oliver, JL. Is a fatigue index a worthwhile measure of repeated sprint ability? *Journal of Science and Medicine in Sport* 12: 20–23, 2009.

43. Oliver, JL, Williams, CA, and Armstrong, N. Reliability of a field and laboratory test of repeated sprint ability. *Pediatric Exercise Science* 18: 339–350, 2006.

44. Salaj, S and Markovic, G. Specificity of Jumping, Sprinting, and Quick Change-of-Direction Motor Abilities: *Journal of Strength and Conditioning Research* 25: 1249–1255, 2011.

45. Schultz, FA, Cavazzoni, P, Carnevale, RV, Abad, CCC, Kobal, R, Pereira, LA, et al. Speed and power predictors of change of direction ability in elite snow athletes. *Journal of Human Sport and Exercise* 10, 2015.Available from: http://hdl.handle.net/10045/57523

46. Sheppard, JM, Gabbett, T, Taylor, K-L, Dorman, J, Lebedew, AJ, and Borgeaud, R. Development of a repeated-effort test for elite men's volleyball. *International Journal of Sports Physiology and Performance* 2: 292–304, 2007.

47. Sides, DL. Kinematics and kinetics of maximal velocity sprinting and specificity of training in elite athletes. University of Salford, 2015 [cited 2017 May 20].Available from: http://usir.salford.ac.uk/id/eprint/34332

48. Spencer, M, Bishop, D, Dawson, B, and Goodman, C. Physiological and metabolic responses of repeated-sprint activities. *Sports Medicine* 35: 1025–1044, 2005.

49. Spencer, M, Fitzsimons, M, Dawson, B, Bishop, D, and Goodman, C. Reliability of a repeated-sprint test for field-field hockey. *Journal of Science and Medicine in Sport* 9: 181–184, 2006.

50. Spencer, M, Lawrence, S, Rechichi, C, Bishop, D, Dawson, B, and Goodman, C. Time–motion analysis of elite field field hockey, with special reference to repeated-sprint activity. *Journal of Sports Sciences* 22: 843–850, 2004.

51. Spiteri, T, Newton, RU, Binetti, M, Hart, NH, Sheppard, JM, and Nimphius, S. Mechanical determinants of faster change of direction and agility performance in female basketball athletes. *The Journal of Strength & Conditioning Research* 29: 2205–2214, 2015.

52. Swinton, PA, Lloyd, R, Keogh, JW, Agouris, I, and Stewart, AD. Regression models of sprint, vertical jump, and change of direction performance. *The Journal of Strength & Conditioning Research* 28: 1839–1848, 2014.

53. Turner, AN, and Stewart, PF. Repeat sprint ability. *Strength & Conditioning Journal* 35: 37–41, 2013.

54. Watts, D. A brief review on the role of maximal strength in change of direction speed. *Journal of Australian Strength and Conditioning* 23: 100–108, 2015.

55. Wierike, SCM te, Tromp, EJY, Meerhoff, LRA, Coelho-e-Silva, MJ, Elferink-Gemser, MT, and Visscher, C. Reproducibility and validity of the STARtest: a test to monitor the change-of-direction speed and ball control of youth basketball players: Running head: reproducibility and validity of the STARtest. *Annals of Research in Sport and Physical Activity* 9–24, 2015.

56. Wong, D, Chan, G, and Ward Smith, A. Repeated-sprint and change-of-direction abilities in physically active individuals and soccer players: Training and testing implications. *The Journal of Strength & Conditioning Research* 26: 2324–2330, 2012.

57. Young, WB, McDowell, MH, and Scarlett, BJ. Specificity of sprint and agility training methods. *The Journal of Strength & Conditioning Research* 15: 315–319, 2001.

58. Young, WB, Miller, IR, and Talpey, SW. Physical qualities predict change-of-direction speed but not defensive agility in Australian Rules football. *The Journal of Strength & Conditioning Research* 29: 206–212, 2015.

APPENDIX A: SUBJECT INFORMATION SHEET

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I would like to invite you to take part in a research study, organised by myself Murray Barratt MSc student at St Mary's University. The study will be conducted at the English Institute of Sport (EIS), Bisham Abbey, UK. Before you decide to participate you need to understand why the research is being done and what it will involve for you. Please take time to read the following information carefully. Ask questions if anything you read is not clear or you would like more information. Take time to decide whether or not to take part.

Title of the project

The effects of fatigue on step characteristics and physical determinants of repeat 20m-shuttle performance in male and female elite hockey players.

Purpose and value of the study

Hockey is a high intensity; repeat sprint invasion sport, therefore those players who are able to effectively accelerate, decelerate and change direction have an advantage over their opponents. The purpose of this study is to determine the relationship between fatigue, step characteristics and repeat 20m shuttle performance and outline the physical determinants that impact this. The results from this investigation could influence training prescription to improve repeat sprint and change of direction performance in your team.

Your participation in the research project

You have been selected as a possible participant in this study because you fall in the category of elite hockey players. Taking part in this study is your choice and agreement to participate should not compromise your legal rights if something goes wrong. If you refuse to participate, this will not affect any rights or benefits you normally have. You may stop your participation in the study at any time without any penalty or loss of benefits.

If you decide to take part in this research study, you will be required to perform a countermovement jump test and a repeated 20m-shuttle (20m + 20m) test with a 180° change of direction. Prior to performing the tests you will perform a standardised warm up as well as familiarisation with the testing procedures.

During countermovement jump testing you will perform 1 set of 3 maximal effort jumps in a 20-30 second period; this can be repeated to ensure you have produced your best result.

During repeated 20m-shuttle testing you will perform 8x20m-shuttles (20m + 20m shuttle with active 20m recovery) on a rolling 30-second clock. The duration of the sprint will dictate the recovery available within the rolling 30 seconds. The recovery performed is active and you are required to complete a 10m shuttle (total 20m) in your recovery period.

Your wellbeing

If you choose to participate in the study, you will be told of any important information learned during the course of the study that may affect your health, welfare or willingness to take part. The investigator may still choose to stop your participation in this study if he thinks it is in your best medical interest.

Confidentiality

All information that is collected about you during the course of the research will be kept strictly confidential. You will be referred to by a unique code, and any information about you will have your name and address removed so that you cannot be recognised. A master list identifying participants to the research codes data will be held on a password protected computer. Any electronic data will be stored on a password-protected computer.

YOU WILL BE GIVEN A COPY OF THIS FORM TO KEEP TOGETHER WITH A COPY OF YOUR CONSENT FORM

APPENDIX B: SUBJECT CONSENT FORM

St Mary's University,

Waldegrave Road, Strawberry Hill, Twickenham,

London TW1 4SX

T: 020 8240 40000 / F: 020 8240 4255

www.stmarys.ac.uk

Name of Participant: ____

Title of the project: The effects of fatigue on step characteristics and physical determinants of repeat 20m-shuttle performance in male and female elite hockey players.

Main investigator: Murray Barratt

Email(s): murray.barratt@eis2win.co.uk or 145387@stmarys.ac.uk

Members of the research team: Andy Hudson, Stephen Patterson

1.I agree to take part in the above research. I have read the Participant Information Sheet, which is attached to this form. I understand what my role will be in this research, and all my questions have been answered to my satisfaction.

2.I understand that I am free to withdraw from the research at any time, for any reason and without prejudice.

3.I have been informed that the confidentiality of the information I provide will be safeguarded.

4.I am free to ask any questions at any time before and during the study.

5.I have been provided with a copy of this form and the Participant Information Sheet.

Data Protection: I agree to the University processing personal data that I have supplied. I agree to the processing of such data for any purposes connected with the Research Project as outlined to me.

Name of participant (print):………………………………………………………………

Signed………………..………………… Date…………………………..........

If you wish to withdraw from the research, please complete the form below and return to the main investigator named above.

Title of Project: The effects of fatigue on step characteristics and physical determinants of repeat 20m-shuttle performance in male and female elite hockey players.

I WISH TO WITHDRAW FROM THIS STUDY

Name (print):____

Signed: ___________________________________ Date: ______________________

APPENDIX C: ETHICS APPLICATION FORM

St Mary's University

Ethics Sub-Committee

Application for Ethical Approval (Research)

This form must be completed by any undergraduate or postgraduate student, or member of staff at St Mary's University, who is undertaking research involving contact with, or observation of, human participants.

Undergraduate and postgraduate students should have the form signed by their supervisor, and forwarded to the School Ethics Sub-Committee representative. Staff applications should be forwarded directly to the School Ethics Sub-Committee representative. All supporting documents should be merged into one PDF (in order of the checklist) and clearly entitled with your Full Name, School, Supervisor.

Please note that for all undergraduate research projects the supervisor is considered to be the Principal Investigator for the study.

If the proposal has been submitted for approval to an external, properly constituted ethics committee (e.g. NHS Ethics), then please submit a copy of the application and approval letter to the Secretary of the Ethics Sub-Committee. Please note that you will also be required to complete the St Mary's Application for Ethical Approval.

Before completing this form:

- **Please refer to the University's Ethical Guidelines. As the researcher/ supervisor, you are responsible for exercising appropriate professional judgment in this review.**
- **Please refer to the Ethical Application System (Three Tiers) information sheet.**
- **Please refer to the Frequently Asked Questions and Commonly Made Mistakes sheet.**
- **If you are conducting research with children or young people, please ensure that you read the Guidelines for Conducting Research with Children or Young People, and answer the below questions with reference to the guidelines.**

Please note:

In line with University Academic Regulations the signed completed Ethics Form must be included as an appendix to the final research project.

If you have any queries when completing this document, please consult your supervisor (for students) or School Ethics Sub-Committee representative (for staff).

St Mary's University Twickenham London

St Mary's Ethics Application Checklist

The checklist below will help you to ensure that all the supporting documents are submitted with your ethics application form. The supporting documents are necessary for the Ethics Sub-Committee to be able to review and approve your application.

Please note, if the appropriate documents are not submitted with the application form then the application will be returned directly to the applicant and may need to be re-submitted at a later date.

	Enclosed? (delete as appropriate)		Version No
Document	Yes	Not applicable	
1. Application Form	Mandatory		
2. Risk Assessment Form	Yes		
3. Participant Invitation Letter		N/A	
4. Participant Information Sheet	Mandatory		

5. Participant Consent Form	Mandatory		
6. Parental Consent Form		N/A	
7. Participant Recruitment Material - e.g. copies of Posters, newspaper adverts, website, emails		N/A	
8. Letter from host organisation (granting permission to conduct the study on the premises)	Yes		
9. Research instrument, e.g. validated questionnaire, survey, interview schedule		N/A	
10. DBS (to be sent separately)		N/A	
11. Other Research Ethics Committee application (e.g. NHS REC form)		N/A	
12. Certificates of training (required if storing human tissue)		N/A	

I can confirm that all relevant documents are included in order of the list and in one PDF document (any DBS check to be sent separately) named in the following format: *Full Name, School, Supervisor*.

Signature of Applicant:

Signature of Supervisor:

Ethics Application Form

1) Name of proposer(s)	Murray Barratt
2) St Mary's email address	145387@stmarys.ac.uk
3) Name of supervisor	Stephen Patterson

4) Title of project: The effects of fatigue on step characteristics and physical determinants of repeat 20m-shuttle performance in male and female elite hockey players.

5) School or service	Sport, Health and Applied Science
6) Programme (whether undergraduate, postgraduate taught or postgraduate research)	MSc Strength & Conditioning
7) Type of activity/research (staff/undergraduate student/postgraduate student)	Student Postgraduate

8) Confidentiality	
Will all information remain confidential in line with the Data Protection Act 1998?	YES

9) Consent	
Will written informed consent be obtained from all participants/participants' representatives?	YES

10) Pre-approved protocol	
Has the protocol been approved by the Ethics Sub-Committee under a generic application?	NO

11) Approval from another Ethics Committee	
a) Will the research require approval by an ethics committee external to St Mary's University?	NO
b) Are you working with persons under 18 years of age or vulnerable adults?	NO

12) Identifiable risks	
a) Is there significant potential for physical or psychological discomfort, harm, stress or burden to participants?	NO
b) Are participants over 65 years of age?	NO
c) Do participants have limited ability to give voluntary consent? This could include cognitively impaired persons, prisoners, persons with a chronic physical or mental condition, or those who live in or are connected to an institutional environment.	NO
d) Are any invasive techniques involved? And/or the collection of body fluids or tissue?	NO
e) Is an extensive degree of exercise or physical exertion involved?	YES
f) Is there manipulation of cognitive or affective human responses which could cause stress or anxiety?	NO
g) Are drugs or other substances (including liquid and food additives) to be administered?	NO

h) Will deception of participants be used in a way which might cause distress, or might reasonably affect their willingness to participate in the research? For example, misleading participants on the purpose of the research, by giving them false information.	NO
i) Will highly personal, intimate or other private and confidential information be sought? For example sexual preferences.	NO
j) Will payment be made to participants? This can include costs for expenses or time.	NO
k) Could the relationship between the researcher/ supervisor and the participant be such that a participant might feel pressurised to take part?	NO
l) Are you working under the remit of the Human Tissue Act 2004?	NO

13) Proposed start and completion date
Please indicate: • **When the study is due to commence.** • **Timetable for data collection.** • **The expected date of completion.**

Please ensure that your start date is at least 3 weeks after the submission deadline for the Ethics Sub-Committee meeting.
Start Date: 01/03/2017 End Date: 21/05/2017

14)Sponsors/Collaborators
Please give names and details of sponsors or collaborators on the project. This does not include your supervisor(s) or St Mary's University. • **Sponsor: An individual or organisation who provides financial resources or some other support for a project.** • **Collaborator: An individual or organisation who** works on the project **as a recognised contributor by providing advice, data or another form of support.**
Sponsor: English Institute of Sport Collaborator: Andy Hudson (Senior Strength and Conditioning Coach, Great Britain Hockey)

15. Other Research Ethics Committee Approval
• **Please indicate whether additional approval is required or has already been obtained (e.g. the NHS Research Ethics Committee).** • **Please also note which code of practice / professional body you have consulted for your project.** • **Whether approval has previously been given for any element of this research by the University Ethics Sub-Committee.**
None

16. Purpose of the study

In lay language, please provide a brief introduction to the background and rationale for your study. *[100 word limit]*

- **Be clear about the concepts / factors / performances you will measure / assess/ observe and (if applicable), the context within which this will be done.**
- **Please state if there are likely to be any direct benefits, e.g. to participants, other groups or organisations.**

Hockey is a high intensity; repeat sprint (Spencer, Bishop, Dawson, & Goodman, 2005) invasion sport, therefore those players who are able to effectively accelerate, decelerate and change direction have an advantage over their opponents. The purpose of this study is to determine the relationship between step characteristics and repeat 20m shuttle performance and outline the physical determinants that impact this. The results from this investigation could influence training prescription to improve repeat sprint and change of direction performance in this athlete group.

17. Study Design/Methodology

In lay language, please provide details of:

a) **The design of the study (qualitative/quantitative questionnaires etc.)**
b) **The proposed methods of data collection (what you will do, how you will do this and the nature of tests).**
c) **You should also include details regarding the requirement of the participant i.e. the extent of their commitment and the length of time they will be required to attend testing.**
d) **Please include details of where the testing will take place.**
e) **Please state whether the materials/procedures you are using are original, or the intellectual property of a third party. If the materials/procedures are original, please describe any pre-testing you have done or will do to ensure that they are effective.**

This study will use a between-subjects design to determine the relationship between repeated 20m-shuttle performance, step characteristics (maximal step velocity pre/post turn, breaking distance) and physical determinants (peak power production, mean power absorption, eccentric impulse). 50 (25 x male, 25 x female) elite hockey players, will be required to attend 1-2 hours of testing at English Institute of Sport, Bisham Abbey. Subjects will perform a countermovement jump (CMJ) test and a repeat sprint ability (RSA) test. Peak power production, mean force absorption and eccentric impulse will be calculated using a countermovement jump (CMJ) using force plates sampling at 1000Hz (FD4000, Forcedecks NMP Technologies, UK). Subjects will then perform 8 repeated 40m (20:20 shuttle, with 20m active recovery) efforts on a rolling 30 second clock. The time to perform each shuttle will be recorded using Brower Timing Gates (TC Timing System, Brower Timing Systems, USA) and step characteristics will be recorded using Optojump (Optojump Next, Microgate, Bolzano, Italy). In order to determine step characteristics, the peak step velocity, contact times and stride lengths will be recorded. To determine the impact of step characteristics on turn efficiency maximum step velocity pre and post turn will be recorded. Breaking distance will be calculated as the distance from the point of turn when the athlete stops accelerating.

Countermovement Jump (CMJ)

Prior to completing the CMJ test subjects will complete a standardised dynamic warm up comprising:

On a 20m track

1. Jog 20m and back pedal 20m x 4
2. Leg swings
3. Lunges with Overhead lean x 10
4. Walking Single toe touch

5. Carioca

6. Inchworms

7. Spiderman with elbow touch

8. High Knees x 2

9. Butt Kicks x 2

10. Jog squat and Jump x 2

11. A-skips x 2

In place

1. Scorpions x 6

2. Iron Cross x 6

3. CMJ x 5

During testing the subjects will perform 1 set of 3 maximal effort jumps in a 20-30 second period; this can be repeated to ensure the athlete has produced their best result. CMJs will start from a stationary position with the subjects feet symmetrically set approximately shoulder width apart. The subject's hands will remain on their hips throughout the whole movement. The force plates will be zeroed before each trial. The subjects will pause for 1-2 seconds on the force plate before jumping to allow more reliable functioning of the CMJ excel processing template. During the flight phase of the CMJ the subject's knees and hips should remain fully extended, avoiding tucking or piking. The subject's landing point should be as close to take off point as possible.

Repeated Sprint Ability Test (RSA)

Prior to completing the RSA test the subjects will complete a standardised sprint warm up comprising:

Using 40m track

1. Jog and back pedal x 2
2. Inch worms x 5 and accelerate
3. 3 point start (start controlled and build pace over 30m) x 3 at 80%, 90% and 100%
4. Tuck jump x 3 & accelerate 20m x 2 at 90% and 100%

During testing the subjects will perform 8 x 40m (20m: 20m shuttle with active 20m recovery) efforts on a rolling 30 second clock. The duration of the sprint will dictate the recovery available within the rolling 30 seconds. The recovery performed is active with the subject required to complete a 10m shuttle (total 20m) in their recovery period. Performances will be recorded for the 8 sprints The subject must start 1 m behind the timing gate, their foot must touch the line situated at the end of the 20m turning point. Failure to do this means the test will be stopped, the subject will then be rested for 5 minutes and the test repeated. This protocol is an adaptation of the 5 x 6 second cycle test. This test is found to be valid for assessing decrement in repeated 15m maximal sprints (mean time 2.74s), but “it may need to be modified to reflect the common sprint distances found in specific sports” (Bishop, Spencer, Duffield, & Lawrence, 2001). Historical data has shown that the 40m shuttle takes between 6.5 and 7.5 seconds within this specific population and therefore 30 seconds is deemed a suitable timescale for repeated efforts. This is supported by Spencer et al. (2004) who suggested, via a time-motion analysis study, that an RSA test, specific to field hockey, may require as many as six to seven sprints with <21 seconds between sprints and involve an active recovery. The test has been extended to 8 repetitions in order to increase fatigue sensitivity.

Bishop, D., Spencer, M., Duffield, R., & Lawrence, S. (2001). The validity of a repeated sprint ability test. Journal of Science and Medicine in Sport, 4(1), 19–29.

Spencer, M., Lawrence, S., Rechichi, C., Bishop, D., Dawson, B., & Goodman, C. (2004). Time-motion analysis of elite field hockey, with special reference to repeated-sprint activity. Journal of Sports Sciences, 22(9), 843–850.

18. Participants

Please mention:

- **a) The number of participants you are recruiting and why. For example, because of their specific age or sex.**
- **b) How they will be recruited and chosen.**
- **c) The inclusion/exclusion criteria.**
- **d) For internet studies please clarify how you will verify the age of the participants.**
- **e) If the research is taking place in a school or organisation then please include their written agreement for the research to be undertaken.**

- **a) Subjects will include 50 elite hockey players (25 x male, 25 x female).**
- **b) They have been selected for the Great Britain Hockey team and will complete the test as part of their regular monitoring protocol.**
- **c) Only players deemed to be in a suitable physical conditioning by coaches and medical staff will be included in the study.**
- **d) N/A**
- **e) Letter from the English Institute of Sport (Appendix A).**

19. Consent

If you have any exclusion criteria, please ensure that your Consent Form and Participant Information Sheet clearly makes participants aware that their data may or may not be used.

a) Are there any incentives/pressures which may make it difficult for participants to refuse to take part? If so, explain and clarify why this needs to be done
b)
c) Will any of the participants be from any of the following groups?

- **Children under 18**
- **Participants with learning disabilities**
- **Participants suffering from dementia**
- **Other vulnerable groups.**

d) If any of the above apply, does the researcher/investigator hold a current DBS certificate? A copy of the DBS must be supplied separately from the application.

e) How will consent be obtained? This includes consent from all necessary persons i.e. participants and parents.

a) The subjects will be required to take part in countermovement jump testing and repeated 20m-shuttle testing as part of the regular monitoring protocol for GB Hockey. They will likely experience external pressure from their coaches as participants will be required to partake if they are deemed fit. However, all subjects are free to withdraw their data from the study if they wish; they are under no obligation to be included in the study.
b) None of the participants fall into the named groups.
c) None of the above apply.
d) Consent will be obtained using a consent form (Appendix B).

20. Risks and benefits of research/ activity

a) Are there any potential risks or adverse effects (e.g. injury, pain, discomfort, distress, changes to lifestyle) associated with this study? If so please provide details, including information on how these will be minimised. **b) Please explain where the risks / effects may arise from (and why), so that it is clear why the risks / effects will be difficult to completely eliminate or minimise.** **c) Does the study involve any invasive procedures? If so, please confirm that the researchers or collaborators have appropriate training and are competent to deliver these procedures. Please note that invasive procedures also include the use of deceptive procedures in order to obtain information.** **d) Will individual/group interviews/questionnaires include anything that may be sensitive or upsetting? If so, please clarify why this information is necessary (and if applicable, any prior use of the questionnaire/interview).** **e) Please describe how you would deal with any adverse reactions participants might experience. Discuss any adverse reaction that might occur and the actions that will be taken in response by you, your supervisor or some third party (explain why a third party is being used for this purpose).** **f) Are there any benefits to the participant or for the organisation taking part in the research (e.g. gain knowledge of their fitness)?**
a/b) The tests require physical exertion; however, the participants selected are highly trained athletes and should therefore be able to take part without significant risk to their health. **c) No** **d) A medical professional will be on hand to ensure the athlete's safety if there are any adverse physical effects experienced as a result of the study.** **e) The participants will gain knowledge of their ability in the repeated 20m-shuttle test. GB Hockey and English Institute of Sport will gain insight into the athletes' performance and the study may inform future training prescription.**

21. Confidentiality, privacy and data protection

a) What steps will be taken to ensure participants' confidentiality?

- **Please describe how data, particularly personal information, will be stored (all electronic data must be stored on St Mary's University servers).**
- **Consider how you will identify participants who request their data be withdrawn, such that you can still maintain the confidentiality of theirs and others' data.**

b) *Describe how you will manage data using a data a management plan.*

- *You should show how you plan to store the data securely and select the data that will be made publically available once the project has ended.*
- *You should also show how you will take account of the relevant legislation including that relating data protection, freedom of information and intellectual property.*

c) Who will have access to the data? Please identify all persons who will have access to the data (normally yourself and your supervisor).

d) Will the data results include information which may identify people or places?

- **Explain what information will be identifiable.**
- **Whether the persons or places (e.g. organisations) are aware of this.**
- **Consent forms should state what information will be identifiable and any likely outputs which will use the information e.g. dissertations, theses and any future publications/presentations.**

All information that is collected about the participants during the course of the research will be kept strictly confidential. Athletes will be referred to by a unique code, and any information about them will have their name and address removed so they cannot be recognised. A master list identifying participants to the research codes data will be held on a password protected computer as well as the St Mary's University server. Any electronic data will be stored on a password-protected computer.

22. Feedback to participants

Please give details of how feedback will be given to participants:

- **As a minimum, it would normally be expected for feedback to be offered to participants in**

an acceptable format, e.g. a summary of findings appropriately written. • **Please state whether you intend to provide feedback to any other individual(s) or organisation(s) and what form this would take.**
Feedback will be provided to participants via a one-page summary sheet outlining their individual performance and step characteristics.

The proposer recognises their responsibility in carrying out the project in accordance with the University's Ethical Guidelines and will ensure that any person(s) assisting in the research/ teaching are also bound by these. The Ethics Sub-Committee must be notified of, and approve, any deviation from the information provided on this form.

Signature of Proposer(s) Murray Barratt	Date: 01/02/17
Signature of Supervisor (for student research projects) Dr Stephen Patterson	Date: 01/02/17