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ABSTRACT

The purpose of this study was to examine the relationship between individual athletes' physical characteristics and both the peak running intensities and the decline in peak running intensities during competition. Twenty-two professional rugby league athletes (age; 24.1 ± 4.0 years, body mass; 101.4 ± 9.5 kg) underwent a series of physical testing procedures. Peak running intensity was determined using a moving average technique, applied to the speed (m·min^{-1}), acceleration/deceleration (m·s^{-2}) and metabolic power (W·kg^{-1}) during competition, across 10 different durations. The power law relationship was then established, yielding an intercept and slope for the movement variables. Mixed linear models were then used to determine the relationship between physical characteristics and intercept and slope values. There were large, positive relationships between a player's maximal speed and both peak running speeds (ES = 0.56, 90% CI: 0.20 to 0.78) and metabolic power (0.57, 0.21 to 0.79) during competition. In contrast, there were large, negative associations between maximal speed and the rate of decline in running speed (-0.60, -0.81 to -0.27) and metabolic power (-0.65, -0.83 to -0.32) during competition. Similarly, there were negative associations between relative squat strength and the rate of decline in running speed (moderate: -0.41, -0.69 to -0.04) and metabolic power (large: -0.53, -0.77 to -0.17) during competition. The findings of this study demonstrate that a players running intensity during competition is underpinned by the individual athletes physiological qualities. Athletes demonstrating higher maximal speeds in testing were able to maintain higher running intensities over short durations, but had a greater decrease in running intensity as duration increased.

Keywords: GPS; physical performance; intensity; moving-average; team-sport

INTRODUCTION

In team sports, athlete movements are regularly monitored to quantify the imposed physical load, and to increase the understanding of the physiological requirements of competition performance. Global positioning systems (GPS) serve as a method of quantifying such movements, and the establishment of the peak running intensities in matches allows for the subsequent prescription of training (9). This ensures that athletes are adequately prepared for the most demanding phases of competition, as the most demanding phases of competition, quantified by a higher number of repeated sprint efforts, have been associated with tries being scored in rugby league (2). This information can be used to precisely quantify the training undertaken, particularly sport-specific drills and games. However, it is also recognized that physiological qualities, such as intermittent high intensity running ability, influence a player's performance in competition (23). Therefore, it is important to identify which physical parameters are related to the peak running intensities during competition so coaches can train the appropriate qualities and enhance peak running capability.

Given the intermittent nature of team-sport match play, and the constant changing of speed, the importance of acceleration ability has been documented (4). Within the majority of team sports, athletes are in close proximity to their opposition, therefore minimizing the opportunity for expansive running (7). Subsequently, there have been numerous investigations quantifying the acceleration profiles of competition across a range of team sports (6, 15, 26, 29). Typically, research has used predefined acceleration thresholds [e.g. 2.78 $m \cdot s^{-2}$ (1)] to identify the distance covered and time spent or frequency of efforts above these intensities. However, this method of transforming time series data into categorical data has been shown to decrease inter-unit reliability (8), as a non-substantial difference in acceleration magnitude can potentially result in a substantial difference in the measured value. As such, calculating the average absolute acceleration has been demonstrated as a more appropriate method for quantifying the acceleration-based demands of rugby league training and match-play using 10 Hz GPS units (CV = 1.2%; 90% confidence interval (CI) 1.0 to 1.7%) (8). Moreover, given that running intensity can be achieved through high-speed running and acceleration efforts, methods have been developed to quantify the metabolic power (P_{met}) of the movements occurring in team sports (24). Furthermore, the calculation of the P_{met} output may provide a more holistic evaluation of the running undertaken in rugby league, where both accelerated/decelerated and high-speed running are accounted for.

A moving average technique has been recognized as the most appropriate method of quantifying the peak running intensities of team-sport competition, when compared to pre-defined periods (i.e., 5-min blocks) (28). Subsequently, the peak running intensities (quantified using speed, acceleration/deceleration, and metabolic power) of rugby league, rugby union, Australian football, and soccer have been reported (9). Furthermore, a novel application of the power law that quantifies the decrease in running intensity as duration of effort increases (18) has also revealed a strong relationship between the running intensity achieved in team sports for the given duration of the moving average applied (11). Specifically, this method involves fitting a power curve trend-line to this relationship, resulting in a simple calculation for estimating peak match running intensity, for any given duration of time. This calculation can then be used as a reference point for monitoring the intensity of training drills relative to the peak match intensity that an athlete may be exposed to.

The ability to perform intermittent, high-intensity exercise for prolonged periods plays a key role in elite rugby league competition (7). However, in semi-professional players, prolonged high intensity running ability, as measured by the YoYo level 1 Intermittent Recovery (YoYo IR1) test, was not associated with running intensity during competition (16). This was despite measures of lower-body strength being positively associated with the distance covered at low and high speeds, and the number of repeated high-intensity effort bouts performed in competition (16). In contrast, aerobic capacity, as measured by a 1.2 km shuttle test, showed a moderate to large, positive relationship with average speed maintained by the players and the total amount of high-speed running performed during competition (19). Similarly, performance in the 30-15 Intermittent Fitness Test (30-15 IFT) has been shown to exhibit a strong positive relationship with both the average speed and P_{met} output of rugby league interchange players (10). Along with similar observations in Australian football (23) and soccer (5), these findings suggest that well-developed physical capacities are beneficial for whole-match running performance. However, it is unknown if these relationships are also prevalent when examining the peak running intensities in competition. Therefore, the aim of this research was twofold: 1. to examine the relationship between individual athletes' physical characteristics and the peak running intensity achieved during competition; and 2. to examine the relationship between individual athletes' physical characteristics and the decline in peak running intensity during competition.

METHODS

Experimental Approach to the Problem

An observational research design was adopted to investigate the relationship between physical characteristics and both the peak running intensities and decline in peak running intensities as the moving average duration increased. This analysis was conducted on data collected during the Australian National Rugby League (NRL) competition. All physical tests were completed in the final week of preseason, 1 week prior to the commencement of the competitive season.

Subjects

Twenty-two professional male rugby league players (age; 24.1 ± 4.0 years, body mass; 101.4 ± 9.5 kg) were assessed during 26 games within the 2016 NRL season, for a total of 420 individual match observations (18.3 ± 7.3 matches per player, range 2-26). Only players undertaking a minimum of 60 minutes of game time throughout the season we included in the investigation. Participants were classified by playing position as follows (n = number of observations): fullback (n = 23), outside backs (center and wingers, n = 90), hooker (n = 25), halves adjustable (half-back and five-eighth; n = 48), middle forwards (props and locks; n = 139), and edge forwards (second rowers; n = 95). Subjects were informed of the risks and benefits of the study and then gave written informed consent to participate. The study was approved by an institutional ethics committee prior to the commencement of the study (HRE16-142).

Procedures

Physical Performance Tests

Body mass was measured to the nearest 0.1 kg, using calibrated electronic scales (Tanita, Kewdale, Australia). Skinfold thickness was measured at 7 sites (Σ7 skinfold thicknesses: biceps, triceps, subscapular, suprailiac, abdomen, thigh, and calf) using calibrated Harpenden calipers (model number 0120; British Indicators Ltd, St Albans, UK) by a trained anthropometrist (typical error [TE] = 1.4%) using standard laboratory techniques. The lean mass index (LMI) was also calculated as previously proposed for rugby league players (12).

To assess maximal lower-body strength a 3RM back squat was performed using an Olympic-style free-weight barbell. Players warmed up with progressively heavier loads and then attempted a 3RM lift. Following protocols previously detailed to be reliable (CV = 3.5%) (22), players were required to lower their body so that their thighs were past parallel with the floor, and the fully extend the hip and knee joints. The maximal load lifted was then converted to the 1RM loading (22) and expressed relative to body mass, as an indicator of relative lower body strength.

Vertical jump (VJ) was assessed using a contact mat (SpeedMat VerA; Swift Performance; Brisbane, Australia), employing methods previously described (21). The contact mat recorded the flight time and contact time of each single jump. Subjects performed a countermovement with the lower limbs prior to jumping and were required to land in the same body position as take-off. Each test was measured with 3 trials, with approximately 1 minute separating trials. This testing procedure has demonstrated good reliability previously (TE = 2.8%) (21).

The drop jump test was administered as a measure of reactive strength, due to the short duration (<0.25 seconds) and fast stretch shortening cycle (SSC) function of the contraction (30). The reactive strength index (RSI) was calculated as the ratio of jump height (in meters) to contact time (in seconds) using a contact mat (SpeedMat VerA; Swift Performance; Brisbane, Australia) (30). For the drop jump test, subjects were required to stand with both feet on a platform raised 0.3 m above the ground. Athletes placed both hands on their hips to negate the contribution of arm swing, and were instructed to step off the platform and land on 2 feet. Upon contact with the ground, the instruction was given to jump to maximize height and minimize ground contact time. The highest RSI score from three trials was used for analysis, provided that the contact time of the jump was less than 0.25 seconds as to ensure that the jump was an appropriate measure of a fast SSC movement. The reliability of the drop jump test has previously been established (CV = 2.2%) in a group of elite rugby league players (10).

Linear speed was timed to the nearest 0.01 seconds using telemetric electronic timing lights (SpeedLight VerC; Swift Performance; Brisbane, Australia) that possess acceptable reliability (TE = 0.9%) (14). Linear sprinting speed was assessed over a distance of 40 m on an outdoor synthetic track using a foot switch to commence timing (14). A 0- to 10-m split provided a measure of average acceleration (SpAcc), and the 30- to 40-m split represented maximum linear speed (SpMax = 10 m/Split Time). Three repeat trials were completed, separated by a rest period of 3 minutes, and the fastest corresponding split times selected for analysis.

Athletes completed the Yo-Yo Intermittent Recovery test level 1 (YoYo IR1) as a measure of intermittent running ability (20). Two x 20 m shuttles were completed at a progressively increasing speed, controlled by a series of audible tones. Between each running bout, athletes performed a 10 second active recovery period, consisting of 2 x 5 m walking/jogging periods. The total distance covered was recorded as the YoYo IR1 test score. The reliability of YoYo IR1 has been previously reported (ICC = 0.98, TE = 4.9%) (20).

Match Activity Profile

During matches, athletes' movements were recorded with a portable GPS unit (GPSports, HPU Units; 5 Hz), fitted into a custom-made pouch in their playing jersey. A limitation of the GPS units used in this investigation was that the Horizontal Dilution of Precision (HDOP) was not provided in the GPS trace, however the number of satellites received during data collection was monitored. Upon completion of each match, data were downloaded using the appropriate proprietary software (GPSports™ TeamAMS software; Release R1 2016.5), where a raw speed trace ($m \cdot s^{-1}$) was exported and further analyzed using customized software (R, v R-3.1.3.). Specifically, speed was calculated as distance covered per unit of time ($m \cdot min^{-1}$). Further to this, the absolute instantaneous acceleration/deceleration ($m \cdot s^{-2}$) of the subject was calculated as the rate of change in speed, regardless of the direction of change, and was considered reflective of the absolute acceleration/deceleration requirement of the activity (8). Metabolic power was calculated using methods detailed previously (13, 24), inclusive of both acceleration/deceleration and speed-based movements. A moving average analysis technique was then applied to each of the output variables, using ten different durations (i.e., 1 to 10 minutes), and the peak value achieved throughout each match for each variable was recorded.

To quantify the relationship between moving average duration and running intensity, each of the three peak intensity measures were evaluated relative to the moving average duration, as a power law relationship (18). A power law relationship between two variables (*x* and *y*) can be given by the equation:

$$y = cx^n \quad [1]$$

where *n* and *c* are constants. A plot of log (*x*) against log (*y*) results in a straight line with slope *n*, and intercept of c^e (18). Linear regression revealed the values for *n* and *c* for each variable within each match file. The exponential of *c* was calculated, and therefore a predictive equation of running intensity (*i*) as a function of time (*t*) was achieved, using the formula:

$$i = ct^n \quad [2]$$

An individual example of the calculation of the power law relationship is provided in Figure 1. For each match observation, the power law relationship was established, yielding an intercept and slope for each of the 3 variables (speed intercept [SpdInt] and slope [SpdSlope], acceleration intercept [AccInt] and slope [AccSlope], and P_{met} intercept [P_{met}Int] and slope [P_{met}Slope])

Statistical Analyses

Linear mixed effects models were used to determine the effect of various physical characteristics on the intercept and slope of the 3 movement variables. In the model design, fixed effects included GPS movement variables, and individual athletes as random effects, that were nested within individual match files. As the focus of this investigation was to examine the relationship between an individual's physical qualities and there running intensity during competition, athlete identification was included as a random effect. Although these athletes were categorized per positional group throughout the season, within the initial model design individual athletes were nested within positional group. However, positional group did not account for any variance in the model (i.e. there was no substantial variability between positions) and the model information criteria was reduced, therefore positional group was subsequently removed from the final model design. The *t* statistics from the final models were converted to Effect Size (ES) correlations (*r*) (25), that were further evaluated using magnitude-based inferences (17). The effect size correlations were described as; <0.1, trivial; 0.1-0.3, small; 0.3-0.5, moderate; 0.5-0.7, large; 0.7-0.9, very large; 0.9-0.99, almost perfect; 1.0, perfect, and their associated 90% CL. These correlations were considered practically important if there was a >75% likelihood of the correlation exceeding the smallest worthwhile difference (0.10) and are described as; 75-95%, likely, 95-99% very likely and

>99%, almost certainly % (17). All analyses were conducted in R Studio statistical software (V 0.99.446).

RESULTS

The mean ± SD number of satellites received during data collection was 7.8 ± 1.4. The results for the physical performance tests are presented in Table 1. For the three metrics examined, the mean intercept and slope values from the power analyses by position are displayed in Table 2. Associations between the each of the physical performance tests and competition running intensity are illustrated in Figure 2.

DISCUSSION

The purpose of this investigation was to quantify the relationship between individual players' physical characteristics and both the peak running intensity achieved during competition, and the decline in peak running intensity as duration increases. Despite the inherent variability of the movements of rugby league players during competition (19), this investigation observed that both high speed running ability and prolonged intermittent running performance influenced the running speed achieved and maintained by players in competition. Notably, faster athletes displayed greater peak running intensities over short duration, as indicated by moderate relationships with both SpdInt and P_{met}Int. Further, there was a moderate, positive relationship between an athletes' relative lower body strength and P_{met}Int. In contrast, high speed running ability (i.e., maximal speed) exhibited a large, negative relationship with short duration peak acceleration outputs (AccInt). It was observed that faster and stronger athletes demonstrated a greater decrease in match running intensity as measured by SpdSlope and P_{met}Slope. This suggests that a balance should be sought between developing an athlete's maximal sprint speed and strength, whilst simultaneously enhancing the ability to maintain running intensity over longer durations. As such, testing battery inclusive of maximal sprinting speed, strength, and intermittent running ability can provide an assessment of an athletes strength and weaknesses in specific physical qualities.

There were only trivial relationships between lower body power (vertical jump) and any of the chosen running performance metrics. This is in somewhat contrast to previous work (16), where it was demonstrated that lower body strength was related to the volume of both high and low-intensity running. It was evident, however, that relative lower body strength was related to the P_{met}Int (ES: 0.32; 90% CL: -0.09 to 0.63) which may be partly explained by the need for explosive leg power during accelerated running (31). Relative lower body strength had a moderate negative relationship with the rate of decrease in running intensity quantified by SpdSlope (-0.41, -0.04 to -0.69) and P_{met}Slope (-0.53, -0.17 to -0.77). This negative relationship between relative lower body strength and the decline in running intensity (as quantified by SpdSlope and P_{met}Slope) may be due to longer durations of activity during competition involving multiple submaximal accelerations, rather than isolated maximal accelerations. In this regard, the density of the accelerations would become more important rather than one off sprinting or acceleration efforts.

The power law analysis of the peak running intensity over increasing moving average duration was developed as a method to estimate the peak running intensities that occur in team sports (9). When examining the peak running intensity of competition, both the speed and acceleration intercepts were slightly higher than those previously reported for rugby league (9). There was a clear moderate positive relationship between YoYo distance and peak speed (0.45, 0.07 to 0.71) output during games. In addition there was an unclear moderate positive relationship between YoYo distance and peak Metabolic Power output in games (0.31, -0.10 to 0.63). The lack of a clear relationship between YoYo distance and peak Metabolic Power during competition may be the frequent contact and wrestling components of rugby league detracting from the running intensity of the players (15). Although P_{met} encompasses the acceleration and deceleration that occurs in rugby league, a large proportion of the game is still not accounted for during contact. Perhaps other internal measures, such as heart rate, need to be included when examining running intensity to provide an even more holistic overview of the demands of competition.

Team-sport competition is typically characterized by an intermittent and chaotic running pattern, as athletes are often required to react to external cues such as movement of opposition players (29). As such, it may be that the YoYo IR1 test utilized within the present study is not reflective of this running profile, which may partly explain the poor relationships reported with measures of the decline in running intensity as moving average duration increased. During the YoYo IR1 test, each repeat effort that occurs involves covering a distance of 40 m, with only one change of direction effort (20). In comparison, in rugby league competition a large proportion of the running occurs within a 10 meter onside zone (7). The average final level in the YoYo for the athletes assessed equates to a running speed of ~250 $m \cdot min^{-1}$, approximately 40% greater than the peak running speeds achieved during competition (~180 $m \cdot min^{-1}$) (9). Despite the YoYo being related to the peak running speeds over short durations (i.e., SpdInt), it may be that a running test that examines a player's ability to performed repeated accelerations may be of more appropriate to discriminate the peak running abilities of rugby league competition. Our finding that a player's maximal speed was negatively associated with the peak accelerations displayed in a game (i.e., AccelInt) would suggest that faster players were not able to perform continuous acceleration/deceleration efforts, even over short durations. As such, it may be more appropriate to develop a repeat sprint/acceleration test over a shorter distance (5 to 10 m) that mimics the movements of rugby league players during competition. Indeed, research examining repeated acceleration efforts in soccer referees reported a large discrepancy between repeated acceleration efforts and repeat sprint efforts (3). As such, further work in clarifying the relationship between repeated acceleration ability and running intensity during team sports is required, and this acceleration ability is also likely to be position specific.

The rate of decline in running intensity as moving average duration increased was similar to previous studies (9), and also similar across the running intensity measures assessed. It has been suggested that this decline is largely determined by the nature of the game, as players are restricted in maintaining running intensity due to stoppages such as refereeing decisions and point-scoring occasions (7). However, a novel finding of the present study was that faster players (i.e. greater maximal speed) exhibited a faster rate of decline in running intensity across the moving averages examined, evidenced by the large negative relationships between maximal running speed and both SpdSlope and P_{met}Slope. This inherent decrease in running speed could possibly be the result of the faster players having a higher proportion of fast twitch fibres, that when required to sustain running intensities over longer duration, fatigue to a greater extent (27). As such, the development of both maximal speed, and the ability to repeat high speed efforts, would form a crucial component in the physical development of elite rugby league players.

PRACTICAL APPLICATIONS

There is a need to examine the ability to perform multiple accelerations in a more specific manner. Although technology such as GPS allows for the ongoing monitoring of athletes during training and competition, there is still a place for standalone fitness tests to assess the strengths and weaknesses of athletes. Although these tests in isolation may not be related to the running intensities displayed in competition, they can give useful information in the physical development of the players. Developing a specific repeat acceleration test of rugby league players may provide more specific information regarding an individual's ability to perform the acceleration demands of competition. For example, a protocol similar to the YoYo IR1, but over shorter distances, may more closely mimic the running demands of competition. At present, micro-technology cannot quantify the loading demands during the contact and wrestle components of competition. It appears that this lack of information dramatically effects any relationships between physical measures and the running intensities displayed by the players. Future research should investigate the quantification of the intensity of contact, perhaps via assessment of internal responses (e.g., heart rate response) to loading.

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Figure Captions

Figure 1: An example of the calculation of the power law relationship of speed ($m \cdot min^{-1}$) for an individual player. The raw data for speed ($m \cdot min^{-1}$) and duration if logged to provide a linear relationship from which the slope and intercept can be calculated.

Figure 2: Effect size correlations between physical performance tests and peak running outputs. The top panel (A) presents the relationship between the physical tests and the intercept for each speed, acceleration and P_{met} achieved during competition. The bottom panel (B) presents the relationship between the physical tests and the decline in speed, acceleration and P_{met} as duration increases. Shaded area represents a moderate effect size, while the dashed line (---) represents a large effect size correlation. The error bars represent 90% confidence limits.

Tables

Table 1: Subject physical performance characteristics.

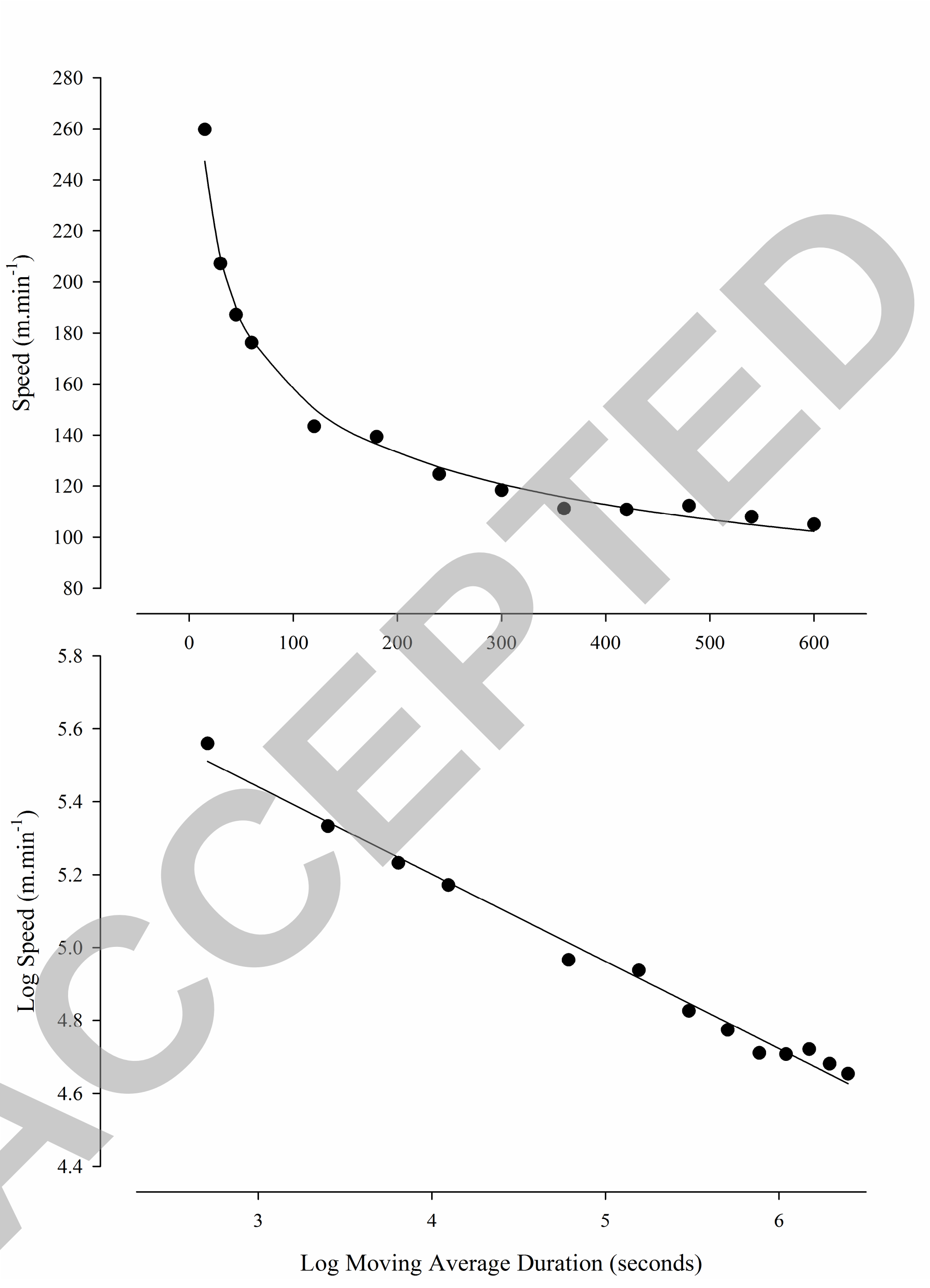
Physical measures	**Mean** ± SD	**Range**
Body Mass (kg)	101.4 ± 9.5	86.7 - 121.5
∑7 Skinfolds (mm)	50.5 ± 8.6	36.8 - 72.0
Lean Mass Index ($kg \cdot mm^{0.16}$)	54.2 ± 4.7	46.2 - 63.5
1RM Relative Back Squat ($kg \cdot kg^{-1}$)	2.0 ± 0.2	1.6 – 2.4
Vertical Jump (cm)	64.8 ± 6.6	51.0 - 78.0
Reactive Strength Index ($cm \cdot s^{-1}$)	191 ± 33	144 - 259
10 metre Sprint (s)	1.57 ± 0.12	1.44 - 2.04
Maximal Speed ($m \cdot s^{-1}$)	8.8 ± 0.4	8.1 - 9.5
YoYo IR1 Distance (m)	1876 ± 264	1480 - 2400

Data are presented as mean ± SD and range (minimum – maximum values).

TABLE 2: The slope and intercept values for running intensity (Speed, Acceleration and P_{met}) by positional group.

Variable	Hooker	Middle Forward	Edge Forward	Adjustable	Outside Back	Fullback
SpdInt	174 ± 9	173 ± 17	171 ± 15	182 ± 16	182 ± 12	195 ± 12
SpdSlope	-0.23 ± 0.03	-0.25 ± 0.04	-0.24 ± 0.04	-0.25 ± 0.03	-0.28 ± 0.04	-0.25 ± 0.04
AccInt	1.25 ± 0.06	1.27 ± 0.09	1.29 ± 0.10	1.29 ± 0.08	1.19 ± 0.11	1.24 ± 0.07
AccSlope	-0.21 ± 0.02	-0.22 ± 0.04	-0.21 ± 0.03	-0.20 ± 0.03	-0.22 ± 0.04	-0.20 ± 0.02
P_{met}Int	17.2 ± 0.7	17.8 ± 1.6	17.6 ± 1.5	18.9 ± 1.9	18.8 ± 1.7	20.0 ± 1.3
P_{met}Slope	-0.24 ± 0.02	-0.27 ± 0.04	-0.26 ± 0.03	-0.27 ± 0.03	-0.31 ± 0.04	-0.28 ± 0.04

Figure 1



280
260
240
220
200
180
160
140
120
100
80
Speed (m.min-1)
0
100
200
300
400
500
600
5.8
5.6
5.4
5.2
5.0
4.8
4.6
4.4
Log Speed (m.min-1)
3
4
5
6
Log Moving Average Duration (seconds)