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Article

The Effect of High Intensity Intermittent Exercise on Power Output for the Upper Body

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Abstract: The aim of the present study was to examine and measure high intensity, intermittent upper body performance, in addition to identifying areas of the body that affect the variance in total work done during the 5 × 6 s sprint test. Fifteen males completed an upper body 5 × 6 s sprint test on a modified electro-magnetically braked cycle ergometer, which consisted of five maximal effort sprints, each 6 s in duration, separated by 24 s of passive recovery. A fly wheel braking force corresponding to 5% of the participants' body weight was used as the implemented resistance level. Body composition was measured using dual-energy X-ray absorptiometry (DEXA). Percent (%) decrement was calculated as 100 − (Total work/ideal work) × 100. Significant ($P < 0.05$) differences were found between sprints for both absolute and relative (W, $W \cdot kg^{-1}$, $W \cdot kg^{-1}$ Lean body mass (LBM) and $W \cdot kg^{-1}$ Upper body lean body mass (UBLBM)) peak (PP) and mean (MP) power. The % decrement in total work done over the five sprints was 11.4%. Stepwise multiple linear regression analysis revealed that UBLBM accounts for 87% of the variance in total work done during the upper body 5 × 6 s sprint test. These results provide a descriptive analysis of upper body, high intensity intermittent exercise, demonstrating that PP and MP output decreased significantly during the upper body 5 × 6 s sprint test.

Keywords: upper body; intermittent; high intensity; exercise; 5 × 6 s; sprint, RSA

1. Introduction

There are significant differences in neuromuscular and cardiovascular function between the upper and lower body at rest and during exercise [1,2]. The upper body is reported to have a higher percentage of type II fibers [3] and extract less oxygen during exercise indicating a greater reliance on anaerobic pathways, compared to that of the lower body [2]. Additionally, differences in peak and mean power during the Wingate test have also been reported between the upper and lower body even when normalized for active muscle mass [4]. Taken together these studies would appear to suggest significant differences exist between upper and lower body anaerobic performance. Similarly a recent study also found no correlation between the upper and lower body anaerobic performance in semi-elite rugby league players [5]. These findings are extremely pertinent as a number of sports which are intermittent in nature require intense exercise efforts using predominantly the upper body musculature.

High intensity, intermittent exercise is an important component of many team and individual sports that involve short periods of high intensity exercise followed by periods of rest or recovery [6]. The ability to perform repeated maximal efforts (<10 s) has previously been defined as repeat sprint ability (RSA) [7,8]. RSA has been shown to be an essential determinant in the outcome of match-play, with small decrements in ability resulting in significantly reduced performance [6]. Moreover, it has been suggested that athletes with superior RSA would have an increased likelihood to perform at a higher power output level or speed compared to those athletes who have a reduced ability to perform repeated sprints [6].

While the majority of studies have examined the RSA of the lower body, high intensity, intermittent upper body exercise has also been shown to be an important component of many sports such as rugby league, rock climbing and wrestling [5,9,10]. During both wrestling and rugby league match-play, participants utilise significant upper body musculature to bring their opponent to the ground [11]. Indeed, it has been established that upper body anaerobic power may help to differentiate between successful and less successful wrestlers [12]. However, despite its importance in a number of sports, few studies have examined high intensity intermittent exercise primarily involving the upper body.

Due to a lack of recent studies examining high intensity, intermittent upper body exercise, the purpose of the present study was to measure RSA during the 5 × 6 s sprint test. Additionally, correlations between both active and total muscle mass, and performance measures including peak power (PP) and mean power (MP) were also assessed.

2. Materials and Methods

2.1. Participants

Fifteen males (n = 15, 24 ± 3 years, 83.3 ± 12.1 kg, 174 ± 7 cm) volunteered to participate in the study. Participants were not highly trained in any specific sport but participated in regular physical activity, completing ≤3 activity sessions·wk^{-1}. Regular physical activity included walking, jogging, tennis and recreational sports such as touch football and surfing.

2.2. Study Design

All participants reported to the laboratory on two separate occasions which were separated by a minimum of five days. During the first visit, participants completed a medical history questionnaire and the required pre-screening procedures. They completed pre-screening procedures and medical history questionnaires, indicating that all participants were healthy and free from any cardiovascular or neuromuscular irregularities. Upon the fulfilment of this inclusion criteria, participants were then familiarised with the electro-magnetically braked cycle ergometer and 5 × 6 s sprint test protocol. During the second visit, participants completed an upper body 5 × 6 s sprint test. Prior to participation, the experimental procedures and potential risks were explained to the participants and all provided written informed consent. All relevant research ethic applications have been approved by the University of the Sunshine Coast Ethics Committee application reference number (S/09/233), and performed in accordance with the Declaration of Helsinki.

2.3. The 5 × 6 s Sprint Test Protocol

The upper body 5 × 6 s sprint test was conducted on a modified electro-magnetically braked cycle ergometer (EE) (Excalibur Sport, Lode B.V., Groningen, The Netherlands). The EE was fixed to a table with the table fixed to the ground to prevent any movement of the EE during the 5 × 6 s sprint test, with participants being instructed to keep their feet flat on the ground and remain seated throughout the 5 × 6 s sprint test. The seat height and back rest were adjusted so that with the crank position on the opposite side to the body and the hand grasping the handles, the elbow joint was almost in full extension (165°–175°) and the shoulders in line with the centre of the ergometers shaft. When seated, participants were then restrained at the waist with an adjustable seatbelt in an attempt to minimise any unwanted movement and involvement from the lower body musculature. A fly wheel braking force corresponding to 5% of the participants' body weight was used for the upper body 5 × 6 s sprint test [13].

Prior to the commencement of the 5 × 6 s sprint test, participants completed a 5 min warm-up at 50 W which included three short sprint efforts followed by a 5 min recovery. Following the warm-up participants stretched for approximately 3 min before the commencement of the test. Participants were instructed to arm crank as fast as possible during each sprint performance. The 5 × 6 s consisted of five maximal effort sprints, all of which were set at the above resistance and lasted for 6 s in duration. Between each of the five repeated sprints there was a 24 s passive recovery. Participants were given verbal encouragement to maintain their highest possible cadence throughout each 6 s sprint.

2.4. Performance Measures

Power output was recorded by the Wingate version 1.0.7 software (Lode B.V., Groningen, The Netherlands) during the 5 × 6 s sprint test. The following performance measures were determined for each 6 s sprint: PP was calculated as the highest single point of power output (recorded at 0.2 s intervals). MP was the average power output during the 6 s sprint effort.

2.5. Body Composition

Body composition was assessed using dual-energy X-ray absorptiometry (DEXA (model XR36, Norland, Fort Atkinson, WI, USA). The same licensed and experienced technician operated the DEXA for each participant, which was calibrated before all testing with a multi-step wedge phantom of tissue and bone reference material. The CV was 1.0% at 95% confidence level. Whole body values were presented as total mass (kg) and percent fat of total body mass (%) and lean body mass (LBM) (g). Upper and lower body measurements were determined on the basis of bony landmarks via manual analysis. The total lean mass for the arms and the shoulders and the addition of the muscle groups of the back and chest, was measured and reported as the upper body lean body mass (UBLBM). The UBLBM muscles have been reported as active during upper body arm ergometry [14], and as such are reported and referred to as the ACTIVE muscle mass during the upper body 5 × 6 s sprint test. For the lower body, both legs and gluteal muscle groups were measured and reported as lower body lean body mass (LBLBM) [4].

2.6. Other Calculations

The total work done was calculated as the sum of the work done in each of the 6 s sprints. This was achieved by converting the MP output (W) for each sprint into kilojoules (Kj) using the following formula:

Kj = ((MP output × time)/1000)
Kj = ((watts × 6 s)/1000)
Total Work (Kj) = Sprint 1 (Kj) + Sprint 2 (Kj), Sprint 3 (Kj) + Sprint 4 (Kj) + Sprint 5 (Kj)

After the total work (Kj) done was calculated (see above), the ideal work (Kj) and % decrement was calculated using the formulas below [15,16]:

Ideal work (Kj) = (highest of 6s sprints × 5)
Decrement (%) = (100 − (Total work/ideal work × 100))

2.7. Statistical Analysis

All analyses were performed using the IBM SPSS 19.0 program for Windows (Chicago, IL, USA). Data are reported as means ± standard deviation (SD). The distribution of the data was analyzed by the Shapiro–Wilk test and the results showed a normal Gaussian distribution. A stepwise multiple linear regression analysis was used to establish the most important determinants of peak and mean upper body 5 × 6 s sprint test power. Collinearity diagnostics were used to remove predictor variables with strong relationships. A one-way repeated measures analysis of variance (ANOVA) was performed to determine significance differences between each 6 s sprint of the 5 × 6 s sprint test. A stepwise multiple linear regression analysis was used to establish the most important determinants of total work done measured in kilojoules (Kj) during the upper body 5 × 6 s sprint test. Variables included body mass (BM), total lean body mass (LBM), body fat %, trunk lean body mass (TLBM), arm lean body mass (ARMLBM), upper body lean body mass (UBLBM) which was a total of TLBM and ARMLBM and lower body lean body mass (LBLBM). A level of significance of 5% ($P < 0.05$) was adopted in all analyses.

3. Results

The descriptive and anthropometric characteristics of all participants are displayed in Table 1. Participants were all otherwise healthy, physically active males of a similar age. This selection criteria was enforced to ensure a homogenous participant group and minimize the effect of any potentially confounding variables. Performance data from the upper body 5 × 6 s sprint test are displayed in Table 2. Absolute PP output during sprint 1, 2 and 3 was significantly ($P < 0.05$) higher than the PP measured during sprint 4 and 5 respectively. When expressed in relative terms ($W \cdot kg^{-1}$), PP in sprint 1 and sprint 2 was significantly higher than sprint 4 ($P < 0.05$). When expressed relative to lean body mass (LBM) ($W \cdot kg^{-1}$ LBM) and active muscle mass ($W \cdot kg^{-1}$ UBLBM) sprint 1 PP was significantly higher than sprint 4 ($P < 0.05$) and 5 ($P < 0.05$), while sprint 2 PP was significantly higher than sprint 4. The PP achieved during sprint 3 was significantly higher ($P < 0.05$) than that measured during sprint 5 when expressed relative to UBLBM.

Table 1. The descriptive and anthropometric data of study participants (n = 15).

Age (years)	24 ± 3
Height (cm)	174 ± 7
Body mass (kg)	83.3 ± 12.1
Body fat (%)	16 ± 7.9
LBM (g)	6,5305 ± 6905
UBLBM (g)	3,8851 ± 3900
ARMLBM (g)	9120 ± 1428
LBLBM (g)	2,2238 ± 2911

LBM, Lean body mass; UBLBM, Upper body lean body mass; ARMLBM, Arms lean body mass; LBLBM, lower body lean body mass; (cm), centimetres; (kg), kilograms; (%), percent; (g), grams.

Table 2. 5 × 6 s sprint test performance data (n = 15).

Performance Measure	**Sprint 1**	**Sprint 2**	**Sprint 3**	**Sprint 4**	**Sprint 5**
PP (W)	1098.5 ± 217.0	1074.3 ± 205.9	1061.9 ± 172.7	1027.1±182.3 ^{a,b}	1036.2± 57.5 ^{a,c}
MP (W)	537.2 ± 112.4	516.5 ± 113.7	555.1 ± 135.4	509.6 ± 95.2 ^{a,c}	519.9 ± 87.1
PP ($W \cdot kg^{-1}$)	13.5 ± 2.0	13.2 ± 2.0	13.1 ± 1.4	12.6 ± 1.8 ^{a,b}	12.8 ± 1.5
MP ($W \cdot kg^{-1}$)	6.6 ± 1.1	6.3 ± 1.2	6.8 ± 1.5	6.3 ± 0.9 ^{c}	6.4 ± 1.0
PP ($W \cdot kg^{-1}$ LBM)	16.9 ± 2.1	16.6 ± 2.3	16.4 ± 1.7	15.9 ± 2.1 ^{a,b}	16.0 ± 1.5 ^{a}
MP ($W \cdot kg^{-1}$ LBM)	8.3 ± 1.2	8.0 ± 1.4	8.6 ± 1.5	7.9 ± 1.1 ^{c}	8.1 ± 1.0
PP ($W \cdot kg^{-1}$ UBLBM)	28.5 ± 3.5	27.9 ± 3.9	27.7 ± 3.1	26.8 ± 3.6 ^{a,b}	27.0 ± 2.6 ^{a,c}
MP ($W \cdot kg^{-1}$ UBLBM)	14.0 ± 2.0	13.4 ± 2.3	14.4 ± 2.6	13.3 ± 1.9 ^{c}	13.6 ± 1.7

Active muscle mass for the upper body = UBLBM, upper body lean body mass; LBM, lean body mass; PP, peak power; MP, mean power; (W), watts; ($W \cdot kg^{-1}$), watts per kilogram; Data is displayed as mean ± SD: ^{a} $p < 0.05$ from Sprint 1; ^{b} $p < 0.05$ from Sprint 2; ^{c} $p < 0.05$ from Sprint 3.

In comparison, absolute MP output values were only significantly different between sprint 1 and 4 ($P < 0.05$) and sprint 3 and 4 ($P < 0.05$). The only significant difference in relative ($W \cdot kg^{-1}$) MP values occurred between sprint 3 and 4 ($P < 0.05$). Significant differences in MP where identified when expressed relative to LBM (W·kg^{-1} LBM) and active muscle mass (W·kg^{-1} UBLBM) between sprint 3 and 4 ($P < 0.05$).

Predictors of upper body 5 × 6 s sprint performance are displayed in Table 3. Stepwise multiple linear regression analysis revealed that UBLBM accounts for 87% of the variance in total work done during the upper body 5 × 6 s sprint test. The decrement in total work done over the five sprints was 11.4%.

Table 3. Predictors of upper body 5 × 6 s sprint test performance ($n = 15$).

Variable	Adjusted R^2	F value	Predictors	Standardized β coefficient	P
Total work (Kj)	0.871	$F_{1,20} = 143.1, p < 0.001$	UBLBM	0.937	<0.001

(Kj), kilojoules; UBLBM, Upper body lean body mass.

4. Discussion

To the best of our knowledge, the intermittent high intensity 5 × 6 s sprint test (RSA) for the upper body has not previously been investigated in a group of physically active individuals. Upper body intermittent performance has been shown to be a key requirement for a number of sports [6] and in the workplace [17]. Therefore the aim of this study was to measure RSA of the upper body and to determine key predictors of RSA ability.

The main findings of the present study were that peak power (PP) output decreased significantly during the upper body 5 × 6 s sprint test, with an approximate decrement of 11.4% in total work performed. Furthermore, stepwise multiple linear regression analysis revealed that UBLBM was the best predictor of total work done.

The highest peak power (PP) value occurred during sprint 1 with significantly lower values occurring during sprints 4–5. These significant differences remained even when expressed relative to LBM and active muscle mass (UBLBM). Mean power (MP) values were also found to decrease, however were only significantly different between sprints 1 and 4 and sprints 3 and 4. When LBM and UBLBM were taken into consideration, significant differences emerged for mean power output between sprint 3 and 4. The greater decline in PP compared to MP may be related to the inability of the upper body to replenish phosphocreatine stores which has been show to affect PP during lower body repeat sprints [18]. The ability to maintain MP during the repeat sprints may also be due to a greater reliance on the aerobic pathways which provides less rapid energy for power and has shown to increase from 10% to 40% over five repeat sprints [19].

Our findings that the highest peak power value occurred in sprint one and then significantly decreased thereafter is in contrast with most previous studies which have investigated the 5 × 6 s sprint test for the lower body [20–22] where no significant decreases in PP have been observed. Furthermore, while we found PP output to be significantly lower during sprints 4 and 5 compared to sprint 1, a recent study which implemented a lower body 10 × 6 s sprint protocol reported that PP output was significantly less only after sprints 8, 9 and 10 [20]. These conflicting findings between the upper and lower body may be attributed to a number of factors, including differences in muscle fiber type characteristics [2,3], their respective PCr resynthesis rates [23], and H^+ buffering capabilities of the muscle [24]. This is further supported by findings that arm exercises are more sensitive to performance improvements induced by increased buffering capacity than leg exercises [25].

Taken together, this suggests that the more efficient replenishment of PCr stores and removal of waste products from the leg musculature extends the time taken, or number of efforts required, to produce a significant decrement in power output compared to the upper body musculature. Moreover, the increased day to day reliance on the lower body musculature for ambulation compared to the upper body may induce favourable training adaption's which allow for a reduced decrement in RSA. In support of these findings the present study found the % decrement in total work performed across the five sprints to be approximately 11.4% for the upper body which is in agreement with a recent study conducted using elite cross country skiers [26], however differs compared to previous studies which have reported between approximately 5.4% and 8.5% for the lower body in endurance and team athletes respectively [15]. These findings, in conjunction with reports of a significant correlation between blood buffer capacity and RSA [27] further suggests a reduced buffering capacity of the upper body musculature, which consequently leads to a higher decrement in work performed and thus decreased RSA performance.

The present study also reported that UBLBM was found to be the best predictor of total work performed during the upper body 5 × 6 s sprint test. These findings are in contrast to Weber *et al.*, 2006 [4] who reported that body mass (BM) rather than lean body mass (LBM) or arm lean body mass (ARMLBM), was the best predictor of upper body Wingate power. These differences may be attributed to the start-stop nature of the 5 × 6 s sprint test compared to the continuous effort of the Wingate. As a result the Wingate does not have the opportunity to replenish PCr stores as per the 5 × 6 s sprint test but relies more on the glycolytic and aerobic pathways for energy. Our findings of UBLBM being the best predictor in work performed across the five sprints suggests that peripheral factors, such as localised neuromuscular activation, play an important role in upper body sprint initiation and fatigue. In support of this, it has been reported that when fatigue is substantial, *i.e.*, a decrement in performance of >10%, there is a concomitant decline in mechanical performance and peripheral electromyography (EMG) amplitude [28,29], suggesting an inability to fully activate the targeted musculature. While central fatigue may also play a role in fatigue during intermittent exercise recent evidence suggests that further studies are required to better understand the role of neural drive on the aetiology of fatigue during the 5 × 6 s sprint test [6].

5. Conclusions

In summary, the present study found that PP output significantly decreased during the upper body 5 × 6 s sprint test even after LBM and UBLBM was accounted for. Stepwise multiple linear regression analysis revealed that UBLBM was the best predictor of total work performed, with a decrement of approximately 11.4% in total work done during the upper body 5 × 6 s sprint test. The findings from the present investigation suggest that as a result of the diminished capacity of the upper body to perform short duration, high intensity, intermittent exercise a training approach whereby the desired physiological mechanisms targeted and activated during match play and sports performance may in turn lead to improved upper body performance during such exercise. Furthermore, this study highlights the need to investigate the upper body as an independent region, rather than making comparisons or drawing conclusions from findings obtained during lower body, short duration, high intensity, intermittent exercise.

Author Contributions

Leonie Harvey, Matthew Bousson, Chris McLellan and Dale Lovell were involved in study design, data collection, data interpretation, and manuscript writing.

Conflicts of Interest

The authors declare no conflict of interest.

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