



P-ISSN: 2394-1685
E-ISSN: 2394-1693
Impact Factor (ISRA): 4.69
IJPESH 2016; 3(3): 356-360
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www.kheljournal.com
Received: 22-03-2016
Accepted: 23-04-2016

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A comparison of upper and lower body high intensity, repeat sprint ability exercise

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Abstract

Purpose: The present investigation aimed to examine and compare upper and lower body 5x6s performance using a randomized crossover design.

Materials and Methods: Twelve physically active males (24 ± 3 years, 178 ± 6 centimetres (cm), 82.5 ± 12.2 kilograms (kg)) volunteered to complete two 5x6s tests. An electronically braked cycle ergometer was used, with a fly wheel braking force corresponding to 5% and 7.5% bodyweight being used for the upper and lower body 5x6s respectively. The 5x6s consisted of 5 maximal sprints, 6 seconds (s) in duration, separated by 24 s of passive recovery. Body composition was assessed via dual energy x-ray absorptiometry. A one-way repeated measures analysis of variance determined significance differences between the upper and lower body sprint performances.

Results: Peak power was found to be significantly ($P < 0.05$) greater for the lower body for all sprints even when expressed relative to bodyweight ($W \cdot kg^{-1}$) ($P < 0.01$ sprint 1-4, $P < 0.05$ sprint 5), lean body mass ($W \cdot kg^{-1}$ LBM) ($P < 0.01$ sprint 1-4, $P < 0.05$ sprint 5) and active muscle mass ($W \cdot kg^{-1}$ AMM) ($P < 0.001$ sprint 1-5). There was a significant ($P < 0.05$) difference in both percentage decrement in total work and peak power fatigue index (Flp) over the 5 sprints between the upper body and lower body.

Conclusions: The lower body is more powerful than the upper body, even when expressed relative to active muscle mass, with the upper body having a greater decrement in total work and a higher peak power fatigue index compared to the lower body performance.

Keywords: maximal sprint, sport, 5x6s, arms, legs.

1. Introduction

High intensity, intermittent exercise is an important component of many team and individual sports and involves short periods of high intensity exercise followed by brief periods of rest or recovery [1]. The ability to perform repeated maximal efforts (<10 s) during sprint running or cycle ergometry has previously been defined as repeat sprint exercise (RSE) and has been found to be an important predictor of successful sporting performance [1]. While a number of previous studies have examined the response of the lower body to RSE, to our knowledge no studies have examined the effect of RSE on the upper body.

A variety of sports from rock climbing and cross country skiing to wrestling and rugby require repeated bouts of high intensity upper body effort [2-5]. Indeed it has been established that upper body performance may help to differentiate between successful and less successful wrestlers [5]. Furthermore elite rugby league players are required to perform multiple repeated bouts of high intensity exercise during tackling and general match-play [3]. Therefore further research is needed to understand the effect RSE has on upper body performance. In particular the effect of fatigue on power output for the upper body and how this may differ from the lower body.

Previous research has found significant differences in neuromuscular and cardiovascular function between the upper and lower body at rest and during exercise [6, 7]. During high intensity exercise differences in peak and mean power have also been reported between the upper and lower body even when normalized for active muscle mass [8]. Additionally a recent study found no correlation between the upper and lower body anaerobic performance in semi-elite rugby league players [9]. Taken together these studies would appear to suggest significant differences may exist in the upper and lower body response to exercise, however the differences in the response of the upper and lower body to RSE are presently unclear.

Therefore the purpose of the present study was to compare the upper body and lower body response to RSE with a 5x6s arm and leg cycle protocol. Differences in peak (PP) and mean power (MP) and fatigue for the upper and lower body during the RSE will be examined. It is hypothesized that significantly greater decreases in PP and MP and a higher fatigue rate will be seen in the upper body compared to the lower body during the RSE protocol.

2. Materials and Methods

2.1 Participants

Twelve physically active males ($n = 12$) volunteered to participate in the study (See Table 1 for descriptive and anthropometric data). Participants were not routinely participating in regular physical activity, completing ≤ 3 activity sessions \cdot wk $^{-1}$ which included walking, jogging, and weekend sports such as touch football and surfing. All participants completed pre-screening procedures and a medical history questionnaire to ensure they were healthy and free from any cardiovascular or neuromuscular irregularities. 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 submitted, with approval being granted for application reference number (S/09/233).

2.2 Procedures

All participants reported to the laboratory on three separate occasions, with each session being separated by a minimum of 5 days. During the first visit, participants completed a medical history questionnaire and the required pre-screening procedures. The completed pre-screening procedures and medical history questionnaires indicated that all participants were healthy, free from any cardiovascular or neuromuscular irregularities. Upon the fulfilment of this inclusion criteria, participants were then familiarised with the electromagnetically braked cycle ergometer (Excalibur Sport, Lode B.V., Netherlands) which was used for upper body testing and the electronically braked cycle ergometer (Velotron, Racermate, Inc., Seattle, USA) which was used for lower body testing, in addition to being familiarised with the 5x6s protocol. Prior to participation, the experimental procedures and potential risks were explained to the participants and all provided written informed consent. Participants were instructed to maintain their regular eating habits for the duration of the testing period and confirmed prior to each testing session that no supplements of any kind had been introduced into their diet. Computer generated randomisation dictated 5x6s testing order to ensure no practice effect was observed. During the second visit, all participants completed one 5x6s (either upper or lower body, assigned via the aforementioned computer generated randomisation). No sooner than 5 days later all participants returned for the third visit to complete the remaining 5x6s. All testing was performed at the same time of day, under the same testing conditions and supervision in an attempt to minimise any diurnal effect.

2.2.1 Upper Body 5x5s

The upper body 5x6s was conducted on a modified electromagnetically braked cycle ergometer (EE) (Excalibur Sport, Lode B.V., Netherlands). The EE was fixed to a table with the table fixed to the ground to prevent any movement of the EE during the 5x6s sprint test, with participants being instructed to keep their feet flat on the ground and remain seated for the

duration of the 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 restrained at the waist with an adjustable seatbelt in an attempt to minimise the contribution from the lower body. A fly wheel braking force corresponding to 7% body weight was used for the upper body 5x6s.

2.2.2 Lower Body 5x6s

The lower body 5x6s was conducted on an electronically braked cycle ergometer (Velotron, Racermate, Inc., Seattle, USA). The seat height was adjusted so that when the pedal was positioned at the lowest point the knee joint was almost in full extension (approximately 5° of flexion). Participants were instructed to grasp the handlebars and remain seated for the duration of the test. A fly wheel braking force corresponding to 8.5% body weight was used for the lower body 5x6s. The braking forces for the arm and leg fly wheel were based off previous research that found that the selected loads to be the optimal force for power development during the Wingate exercise^[10, 11].

Prior to the commencement of the 5x6s sprint tests, participants completed a 5 min warm-up on the respective cycle ergometer at 50 Watts (W) which included three short sprint efforts followed by a 5min recovery. Following the warm-up participants were encouraged to stretch for approximately 3 min before the commencement of the test. Participants were instructed to arm crank/cycle as fast as possible during each sprint performance. The 5x6s consisted of 5 maximal effort sprints, each of which were initiated from a stationary start, lasting 6 s in duration and separated by 24 s of passive recovery. Participants were given verbal encouragement to maintain their highest possible cadence throughout each sprint. Testing order was randomized to ensure no practice effect was observed.

2.2.3 Measurements

Power output was recorded by the Wingate version 1.0.7 software (Lode B.V., Netherlands) during the 5x6s. The following performance measures were determined for each 6 s sprint; Peak power (PP): calculated as the highest single point of power output (recorded at 0.2 s intervals), Mean power (MP): the average power output during the 6 s sprint effort. 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 mean power output (W) for each sprint into kilojoules (Kj) using the following formula:

$$Kj = \text{mean power output} / \text{time} \times 1000$$

$$Kj = \text{watts} / 6 \text{ s} \times 1000$$

$$\text{Total Work (Kj)} = \text{Sprint 1 (Kj)} + \text{Sprint 2 (Kj)}, \text{Sprint 3 (Kj)} + \text{Sprint 4 (Kj)} + \text{Sprint 5 (Kj)}$$

After the total work (Kj) done was calculated (see above), the ideal work (Kj) and % decrement was calculated using the previously implemented formulas below^[12, 13]:

$$\text{Ideal work (Kj)} = \text{highest 6 s work} \times 5$$

$$\text{Decrement (\%)} = 100 - (\text{Total work} / \text{ideal work} \times 100)$$

In addition the fatigue index for peak power (FIp) was calculated by subtracting the lowest recorded value from the highest recorded value (within each trial) and expressing the difference as a percentage of the highest value.

2.2.4 Body Composition

Body composition was assessed using dual-energy X-ray absorptiometry (DEXA) (model XR36, Norland, Fort

Atkinson, WI). 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 referred to as the active muscle mass (AMM) during the upper body 5x6s. For the lower body, both legs and gluteal muscle groups were measured and reported as lower body lean body mass (LBLBM) [8], and referred to as the active muscle mass (AMM) during the lower body 5x6s.

2.3 Statistical Analysis

All analyses were performed using the IBM SPSS 19.0 program for Windows (Chicago, IL). 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 one-way repeated measures analysis of variance (ANOVA) was performed to determine significance differences in power measurements between the upper and lower body for each 6 s sprint of the 5x6s sprint test. An independent t-test was used to determine differences in percent decrement in total work and FI_p. 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 individuals of a similar age. This selection criteria was enforced to ensure a homogenous participant group and minimize the effect of any potentially confounding variables such as gender, age and training status (Insert Table 1 here). Performance data from the upper and lower body 5x6s are displayed in Table 2. Absolute MP output was significantly (P<0.05) greater for the lower body compared to the upper body during sprints 1,2 and

4 only which remained when expressed relative to bodyweight (W·kg⁻¹) (P<0.01 sprint 1, P<0.05 sprint 2 and 4), lean body mass (W·kg⁻¹ LBM) (P<0.01 sprint 1, P<0.05 sprint 2 and 4) and active muscle mass (W·kg⁻¹ AMM) (P<0.001 sprint 1-5). Absolute PP output was significantly (P<0.05) greater for the lower body compared to the upper body for all sprints. Peak power output remained significantly greater for the lower body 5x6s compared to the upper body 5x6s for all repeat sprints even when expressed relative to bodyweight (W·kg⁻¹) (P<0.01 sprint 1-4, P<0.05 sprint 5), lean body mass (W·kg⁻¹ LBM) (P<0.01 sprint 1-4, P<0.05 sprint 5) and active muscle mass (W·kg⁻¹ AMM) (P<0.001 sprint 1-5). (Insert Table 2 here). There was a significant (P<0.01) difference in the absolute TW performed, with mean values of 13.3, s = 1.8 Kj and 15.2, s = 2.7 Kj being recorded for the upper and lower body 5x6s respectively. When made relative to AMM, the significant (P<0.01) difference in the TW (Kj·kg⁻¹ AMM) performed between the upper and lower body remained. There was a significant (P<0.05) difference in both percentage decrement in total work and FI_p over the 5 sprints between the upper body and lower body respectively (Figure 1).

Table 1: Descriptive and anthropometric data of study participants (n=12)

Age (years)	24 ± 3
Height (cm)	178 ± 6
Body mass (kg)	82.5 ± 12.2
Body fat (%)	16.3 ± 8.1
LBM (g)	64458 ± 6385
UBLBM (g)	38362 ± 3585
ARMLBM (g)	8917 ± 1260
LBLBM (g)	21905 ± 2738

ARMLBM, arm lean body mass; (cm), centimetres; (g), grams; (kg), kilograms; LBM, lean body mass; LBLBM, lower body lean body mass; UBLBM, upper body lean body mass; (%), percent

Table 2 A: comparison of upper body and lower body 5x6s performance data (n =12)

	Sprint 1		Sprint 2		Sprint 3		Sprint 4		Sprint 5	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
PP (W)	702.4 ± 95.2	798.0 ± 166.5 ^a	645.3 ± 89.8	771.4 ± 151.8 ^a	633.7 ± 77.8	750.7 ± 129.3 ^a	616.2 ± 88.0	733.1 ± 130.8 ^a	598.8 ± 66.7	712.4 ± 121.7 ^a
MP (W)	458.5 ± 64.3	536.9 ± 96.5 ^a	442.0 ± 74.1	519.1 ± 100.2 ^a	456.3 ± 87.6	511.9 ± 86.5	430.1 ± 65.4	496.8 ± 94.1 ^a	437.2 ± 46.2	488.6 ± 95.7
PP (W·kg ⁻¹)	8.1 ± 1.1	9.6 ± 1.2 ^b	7.9 ± 1.2	9.2 ± 1.1 ^b	7.7 ± 0.8	8.9 ± 0.9 ^b	7.5 ± 1.1	8.7 ± 0.9 ^b	7.6 ± 0.9	8.5 ± 1.1 ^a
MP (W·kg ⁻¹)	5.6 ± 0.8	6.4 ± 0.6 ^b	5.4 ± 1.0	6.2 ± 0.7 ^a	5.6 ± 1.2	6.1 ± 0.5	5.3 ± 0.8	5.9 ± 0.6 ^a	5.4 ± 0.8	5.9 ± 0.6
PP (W·kg ⁻¹ LBM)	10.2 ± 1.0	12.2 ± 1.8 ^b	10.0 ± 1.2	11.7 ± 1.6 ^b	9.8 ± 1.0	11.3 ± 1.3 ^b	9.6 ± 1.2	11.0 ± 1.3 ^b	9.6 ± 0.8	10.7 ± 1.2 ^a
MP (W·kg ⁻¹ LBM)	7.1 ± 0.8	8.2 ± 1.2 ^b	6.9 ± 1.0	7.9 ± 1.2 ^a	7.1 ± 1.2	7.8 ± 0.9	6.7 ± 0.9	7.6 ± 1.1 ^a	6.8 ± 0.8	7.5 ± 1.1
PP (W·kg ⁻¹ AMM)	17.2 ± 1.8	35.8 ± 5.1 ^c	16.8 ± 2.1	34.3 ± 4.4 ^c	16.6 ± 1.8	33.3 ± 3.6 ^c	16.1 ± 2.1	32.5 ± 3.6 ^c	16.2 ± 1.5	31.6 ± 3.3 ^c
MP (W·kg ⁻¹ AMM)	12.0 ± 1.4	24.2 ± 3.7 ^c	11.5 ± 1.8	23.4 ± 3.6 ^c	11.9 ± 2.0	23.0 ± 2.7 ^c	11.2 ± 1.6	22.4 ± 3.1 ^c	11.5 ± 1.3	22.0 ± 3.0 ^c

AMM, active muscle mass; AMM for the lower body = LBLBM; AMM for the upper body = UBLBM; (Kj), kilojoules; LBM, lean body mass; MP, mean power; PP, peak power; TW, total work; (W), watts; (W·kg⁻¹), watts per kilogram
 Data is displayed as mean ± SD: ^a P<0.05 from upper; ^b P<0.01 from upper; ^c P<0.001 from upper

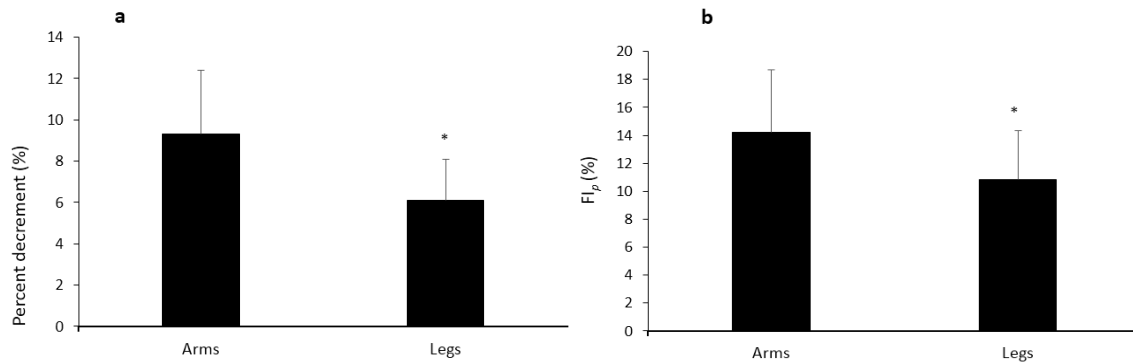


Fig 1a: Percent decrement in total work done and **b.** peak power fatigue index (FIP) recorded for the 5 X 6 sprints for the upper and lower body. * Significantly different $P < 0.05$.

4. Discussion

The main finding of the present study was that there were significant ($P < 0.05$) differences in both absolute (W) and relative ($W \cdot kg^{-1}$) peak and mean power between the upper and lower body 5x6s, with differences remaining even when relative to LBM and AMM. Furthermore, we found that the lower body performed significantly more TW during the 5x6s, with differences remaining even when made relative to active muscle mass ($W \cdot kg^{-1}$ AMM). The lower body also experienced less of a performance decrement in total work done and lower FIP compared to the upper body.

To the best of our knowledge, no previous investigations have examined upper body 5x6s performance despite the significant contribution of high intensity intermittent exercise required for sports such as wrestling, rock climbing and tennis [15-17]. While numerous investigations have examined lower body 5x6s sprint performance in a variety of different sports [12, 18, 19], there is a lack of information available on the effect of high intensity, intermittent exercise for the upper body. As a result, the comparison of upper and lower body 5x6s performance has not previously been investigated within the same participant group.

The present investigation found that the upper body achieved a significantly ($P < 0.05$) lower PP output during each sprint of the 5x6s compared to the lower body, even when relative to both LBM ($W \cdot kg^{-1}$ LBM) ($P < 0.01$) and active muscle mass ($W \cdot kg^{-1}$ AMM) ($P < 0.001$). The greater power output measured relative to both the AMM and LBM would seem to indicate that the lower body has a greater capacity for anaerobic performance. In contrast, it has previously been reported that the musculature of the upper body typically has a higher proportion of type II muscle fibers [17], indicating a greater reliance on anaerobic pathways for energy metabolism [7]. However, a recent investigation which separated the anaerobic energy system into lactic (glycolytic) and alactic (PCr) components, found that the upper body relies to a greater extent on the anaerobic lactic component of the anaerobic energy system during high intensity exercise [20]. Moreover, the 5x6s was designed to minimise the involvement on the anaerobic lactic (glycolytic) component of the anaerobic energy system while maximising the involvement of the anaerobic alactic component via PCr depletion and replenishment. Taken together, this would seem to suggest that the lower body has a greater capacity to both utilise and replenish PCr intramuscular stores during high intensity, intermittent exercise.

The present study found that the upper body had a greater decrement in total work and a higher fatigue index (figure 1) over the 5 sprints compared to the lower body. This may also

be due to the greater capacity of the lower body to both use and replenish PCr stores as a result of a greater oxidative capacity of the lower body musculature [7]. While the 5x6s relies on intramuscular PCr stores for instantaneous energy, PCr replenishment is primarily dependent upon oxidative pathways [21-23]. In support of this, a recent study found that aerobic contribution to the first sprint of a 5x6s protocol was approximately 10%, however increased to approximately 40% by the fifth sprint [24]. These findings suggest that the oxidative characteristics of the lower body musculature in conjunction with the increasing reliance on aerobic pathways during the 5x6s provide the lower body with a greater ability to maximise 5x6s repeat sprint performance compared to upper body.

It must be acknowledged that the training status of the participants involved in the present study may have influenced the upper and lower body's ability to utilise and replenish PCr intramuscular stores. While every effort was made to ensure the participants were not highly trained and from a variety of sports involving both the upper and lower body such as surf lifesaving, tennis, basketball and football, most recreational sports predominantly use the lower body compared to the upper body. Additionally, the lower body musculature is used on a daily basis for mobility and ambulation. Taken together, these factors may have resulted in a slight training effect of the lower body musculature for the participants in the present investigation, possibly leading to favourable oxidative training adaptations.

Another factor that may have influenced the results is the contribution of regional muscle mass to upper and lower body sprint performance. Although muscles other than from the lower body may be involved during lower body cycle ergometry, the present study has used previously identified muscles to determine the AMM during the lower body 5x6s sprint protocol [25]. Similarly to overcome the possible influence of the lower body to upper body performance the participants in the present study remained seated and restrained at the waist, as previously detailed (see Methods). However, it is plausible that AMM during the upper body 5x6s may have also been underestimated by discounting the contribution from the lower body musculature [8].

The present study also found that the lower body experienced less of a performance decrement during the 5x6s compared to the upper body which is in agreement with previous reports for the 30 s WANt [8]. However, we found the % decrement in total work done over the 5 sprints was 14.2% and 10.8% for the upper body and lower body respectively, which is significantly lower than what has been reported previously for both the upper and lower body during the 30 s WANt [8].

While both the 5x6s and 30 s Wan T have an identical work time of 30 s, the 30 s WAnT involves a single bout of maximal effort cycling for a duration of 30 s with no rest periods. The 5x6s on the other hand, is intermittent in nature, with short duration, maximal sprints being separated by brief recovery periods. The intermittent nature of the 5x6s in conjunction with the shorter sprint efforts leads to a greater reliance on ATP/PCr stores for energy metabolism^[26]. Furthermore, the inclusion of brief rest periods to assist recovery during the 5x6s appears to be sufficient enough to restore ATP/PCr stores to near resting levels, in turn resulting in less of a drop off in performance during subsequent sprint efforts.

5. Conclusion

In summary, the present investigation has found that the lower body is capable of performing more total work while recording less of a performance decrement compared to the upper body. Furthermore, the lower body was found to be significantly more powerful than the upper body during the same task, even when expressed in relative terms. As such, sports which require a significant contribution from the upper and lower body should train these regions independently, as specific training adaptations are dependent on the body region and localised musculature. With many team and individual sports requiring a significant contribution from the upper body and being intermittent in nature, these findings highlight the importance of training the upper body and lower body separately. These findings, in conjunction with the different performance determinants that were identified for the upper and lower body suggest that more research is required to help distinguish additional factors which may contribute to the significant differences identified in the present investigation.

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