



The Effect of Previous Wingate Performance Using one Body Region on Subsequent Wingate Performance Using a Different Body Region

by

Leonie Harvey¹, Matthew Bousson¹, Chris McLellan², Dale Lovell¹

The 30 second Wingate Anaerobic Test (WAnT) is the gold standard measure of anaerobic performance. The present investigation aimed to determine if a previous WAnT using one body region significantly affected a subsequent WAnT using a different body region. Twelve male university students ($n = 12$, 23 ± 2 years, 84 ± 16.1 kg, 178.5 ± 7.4 cm) volunteered to complete two repeated WAnT protocols (either lower body WAnT followed by an upper body WAnT or vice versa) on two separate testing occasions. The upper body WAnT was conducted on a modified electromagnetically braked cycle ergometer using a flywheel braking force corresponding to 5% bodyweight. The lower body WAnT was conducted on an electronically braked cycle ergometer using a flywheel braking force corresponding to 7.5% bodyweight. Participants had a 1 minute rest period for transition between WAnTs. Data are reported as mean \pm standard deviation. No significant differences were identified in power indices for the lower body between 30 s WAnTs. When the upper body WAnT was performed 2nd, absolute peak power ($p < 0.01$), mean power ($p < 0.001$) and relative mean power ($p < 0.001$) were significantly lower compared to when the upper body WAnT was performed 1st. The value of maximum revolutions per minute was significantly lower ($p < 0.001$) when the upper body WAnT was performed after the lower body WAnT, compared to when it was performed 1st (193.3 ± 11.4 1st vs 179.8 ± 14.4 2nd). Previous upper body sprint exercise does not significantly affect lower body sprint exercise; however, previous lower body sprint exercise severely compromises subsequent upper body sprint performance.

Key words: repeated, WAnT, upper body, lower body.

Introduction

The 30 second Wingate anaerobic test (30 s WAnT) is one of the most commonly implemented tests for measuring anaerobic performance, as it has been shown to be both a valid and reliable tool in the assessment of anaerobic performance in both athletic (Hawley and Williams, 1991; Horswill et al., 1989; Kounalakis et al., 2009) and clinical populations (Jacobs et al., 2003; Metter et al., 2004). This supramaximal intensity test involves 30 s of all out cycling using either the arms or the legs, both types of this test are performed in a seated

position to minimise the contribution of other untargeted musculature and the momentum which may be generated by the individual's body weight (McLester et al., 2004; Reiser et al., 2002). While the upper and lower body 30 s WAnTs have been extensively researched within the current literature (Beneke et al., 2002; Lovell et al., 2013; Richmond et al., 2011), alternating upper and lower body repeated WAnT performance is yet to be examined.

Examining repeated 30 s WAnT performance is important as many team and

¹ - School of Health and Sport Sciences, Faculty of Science, Health & Education, University of the Sunshine Coast, Sippy Downs, Queensland, Australia.

² - Faculty of Health Sciences and Medicine, Bond University, Robina, Queensland, Australia.

individual sports such as rugby league (Lovell et al., 2013), wrestling (Horswill et al., 1992), cross-country skiing (Mahood et al., 2001; Van Hall et al., 2003) and rock climbing (Bertuzzi et al., 2007; Sheel et al., 2003) require simultaneous or consecutive short duration, explosive efforts from both the upper and lower body. For example, while rugby league appears to be a running based sport, it has been found that an elite rugby league player may make more than 41 tackles per game (Sirotic et al., 2011) with high intensity grappling efforts lasting as long as 35 s (Gabbett, 2008), a similar time taken as the WAnT. Similarly, during cross-country skiing it has been reported that more than 50% of forward propulsion is generated by the upper body (Smith et al., 1989), while the relative arm intensity during continuous ski exercise is equal to approximately 60% of maximal arm VO₂ (Van Hall et al., 2003). These statistics relate only to the upper body efforts required by these sports, overlooking the effect and contribution of any lower body efforts. Consequently, the role of different body regions on subsequent high intensity efforts remains unclear.

Although previous investigations have examined repeated 30 s WAnTs, they included 2 or more WAnTs performed by the same body region, ranging from 10 to 30 s in duration and separated by 1.5 up to 6 min of recovery (Bogdanis et al., 1994, 1996; Kohler et al., 2010; Watt et al., 2002). In one of the first investigations to examine repeated lower body 30s WAnT performance, it was reported that peak power (PP) and mean power (MP) output decreased by approximately 20% in the subsequent lower body 30 s WAnT (Bogdanis et al., 1996). Furthermore, a shift in the energy metabolism was also reported with a 45% decrease in glycolysis from the first lower body WAnT to the second lower body WAnT, with a concomitant increase of approximately 20% in aerobic energy contribution (Bogdanis et al., 1996). While it is clear that repeated lower body 30 s WAnTs have a profound effect on performance, less clear is the effect of upper body 30 s WAnT performance on subsequent lower body 30 s WAnT performance or the effect of lower body 30 s WAnT performance on subsequent upper body 30 s WAnT performance.

Significant contribution of both the upper

and lower body is a requirement in the successful performance of many sports and in turn warrants the division and further investigation into individual components. Therefore, the present investigation aimed to examine the effect of short duration, high intensity exercise using one body region on the subsequent performance of short duration, high intensity exercise using another body region. This was achieved by implementing a randomized crossover design using an upper body 30 s WAnT and lower body 30 s WAnT, with 1 min recovery between efforts. It was hypothesized that subsequent short duration, high intensity upper body exercise would be significantly reduced following a prior short duration, high intensity lower body effort.

Material and Methods

Participants

Twelve male university students ($n = 12$, 23 ± 2 years, 84 ± 16.1 kg, 178.5 ± 7.4 cm) volunteered to participate in the study. The subjects were not highly trained in any specific sport, but participated in physical activity, completing ≤ 3 activity sessions \cdot wk⁻¹. Physical activity included walking, jogging, tennis and recreational sports such as touch football and surfing.

Testing Sessions

All participants reported to the laboratory on three different occasions which were separated by a minimum of 5 days. During the first visit, participants completed a medical history questionnaire and the required pre-screening procedures. It allowed us to state that all participants were healthy and free from any cardiovascular or neuromuscular irregularities. Upon the fulfilment of this inclusion criteria, participants were then familiarized with the electro-magnetically 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) used for lower body testing, in addition to the Repeated 30 s Wingate Anaerobic Test (WAnT) protocol.

During the second visit, participants completed one Repeated 30 s WAnT (either lower body 30 s WAnT followed by an upper body 30 s WAnT or vice versa). During the final visit, participants completed the remaining Repeated 30

s WAnT. Testing order was randomized to ensure no learning effect occurred. Prior to the commencement of the study, the experimental procedures and potential risks were explained to the participants and all provided written informed consent. All relevant research ethics applications had 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.

Repeated WAnT protocol

The upper body 30 s WAnT was conducted on a modified electro-magnetically 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 in the EE during the WAnT (Lovell et al., 2011). Participants sat on a chair (also fixed to the ground) then they were advised to keep their feet flat on the ground and remain seated throughout the WAnT. 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 center of the ergometers shaft.

The lower body 30 s WAnT 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 5% and 7.5% of the participants body weight was used for the upper and lower body, respectively (Dotan and Bar-Or, 1983; Inbar et al., 1996).

Prior to the commencement of the Repeated WAnT, participants completed a 5 min warm-up at 50W which included three short sprint efforts followed by 5 min recovery. Then the participants stretched for approximately 3 min before the beginning of the test. Participants were instructed to arm crank/cycle as fast as possible and were given a 3 s countdown before the set resistance was applied. Verbal encouragement was given to all participants to maintain their

highest possible cadence throughout both WAnTs. Upon completing the first WAnT, participants had a 1 min rest period for transition to the next piece of testing equipment to perform the remaining 30 s WAnT. A time frame of 1 min was selected to ensure adequate time for safe transition to the next piece of testing equipment and to be fully set up, while not allowing so much rest that the subsequent 30 s WAnT would be favourably affected.

Power output was recorded by the Wingate version 1.0.7 software (Lode B.V., Netherlands) and Velotron CS software (RacerMate Inc., Seattle, USA) for the upper and lower body WAnT, respectively. The following WAnT variables were measured: Peak power (PP) was calculated as the highest single point of power output (recorded at 0.2 s intervals). Mean power (MP) was the average power output during the 30 s test. The fatigue index (FI) was reported as a single value that was calculated using Wingate version 1.0.7 software (Lode B.V., Netherlands) and Velotron CS software (RacerMate Inc., Seattle, USA).

Statistical Analysis

All analyses were performed using the IBM SPSS 21.0 program for Windows (Chicago, IL). Data are reported as means \pm standard deviation (SD). An independent t-test was used to determine significant differences in performance measures for the repeated 30 s WAnT within the one body region (eg Arms 1st vs Arms 2nd). Performance measures included: absolute peak power (PP) and mean power (MP) measured in Watts (W), relative PP and MP measured in Watts per kilogram of bodyweight ($W \cdot kg^{-1}$), a fatigue index (FI) and maximum revolutions per minute (Max RPM). The level of significance of 5% ($p < 0.05$) was adopted in all analyses.

Results

Participants were all healthy, physically active males of a similar age. These selection criteria ensured a homogenous participant group and minimized the effect of any potentially confounding variables. Performance data from the repeated 30 s WAnTs are displayed in Table 1. Both absolute (W) and relative ($W \cdot kg^{-1}$) PP and MP did not differ significantly for the lower body 30 s WAnT when performed first, compared to when it was performed 2nd (following the upper

body 30 s WAnT). Conversely, when the upper body 30 s WAnT was performed 2nd (following a lower body 30 s WAnT), absolute PP ($p < 0.01$), MP ($p < 0.001$) and relative MP ($p < 0.001$) were significantly lower compared to when the upper body 30 s WAnT was performed first. The FI for both the arms and legs did not differ significantly between the 1st and 2nd 30 s WAnT efforts. The maximum RPM measured for the legs was not

significantly different between the 1st lower body 30 s WAnT effort compared to when it was performed 2nd (following the upper body 30 s WAnT). The maximum RPM measured for the arms was significantly lower ($p < 0.001$) when the upper body 30 s WAnT was performed after the lower body 30 s WAnT, compared to when it was performed 1st (193.3 ± 11.4 1st vs 179.8 ± 14.4 2nd).

Table 1

Performance measures for the Repeated 30 s WAnT protocols for the arms and legs (N = 12). NB: Comparisons are made within one body region (eg Arms 1st vs Arms 2nd).

Measure	WAnT A		WAnT B	
	Arms (1 st)	Legs (2 nd)	Legs (1 st)	Arms (2 nd)
PP (W)	753.7 ± 150.2	935.8 ± 205.5	931 ± 198.2	706.3 ± 143.4 ^a
MP (W)	568.6 ± 117.4	564.7 ± 98.7	573.2 ± 100.8	484.4 ± 90.1 ^b
PP (W·kg ⁻¹)	7.6 ± 3.6	11.1 ± 1.1	11.1 ± 1.5	8.4 ± 0.9
MP (W·kg ⁻¹)	6.8 ± 0.3	6.7 ± 0.4	6.8 ± 0.4	5.8 ± 0.6 ^b
FI	45.6 ± 12.2	22.3 ± 5.8	22.6 ± 7.4	43.2 ± 11.1
Max RPM	193.3 ± 11.4	180.1 ± 10.3	176.3 ± 10.5	179.8 ± 14.4 ^b

PP, peak power; MP, mean power; (W), watts; (W·kg⁻¹), watts per kilogram;

FI, fatigue index; Max RPM, maximum revolutions per minute;

Data is displayed as the mean ± SD, standard deviation.

^a p < 0.01 from when performed 1st; ^b p < 0.001 from when performed 1st;

Discussion

The main finding of the present investigation was that lower body 30 s WAnT performance was not significantly affected by a previous upper body 30 s WAnT performance. Conversely, the upper body 30 s WAnT was significantly reduced following a lower body 30 s WAnT, confirming our hypothesis. Furthermore, while previous exercise did not significantly affect the maximum RPM achieved during the lower body 30 s WAnT, the maximum RPM for the

upper body 30 s WAnT was significantly reduced following prior leg exercise.

To the best of our knowledge, no previous investigations have examined the effect of preceding, short duration, high intensity sprint efforts on subsequent sprint efforts performed by a different region of the body. The present investigation found that both absolute (W) and relative (W·kg⁻¹) PP output was not significantly different between lower body 30 s WAnT efforts (Table 1), suggesting that prior upper body 30 s

WAnT performance did not significantly impact power output during the lower body 30 s WAnT. Alternatively, it was found that absolute (W) PP output for the upper body 30 s WAnT was significantly ($p < 0.01$) reduced following a lower body 30 s WAnT, indicating that the upper body 30 s WAnT was significantly affected by previous lower body exercise. These findings are in agreement with some (Bogdanis, 2012; Bogdanis et al., 1994), but not others (Halperin et al., 2014) who have attempted to examine the effect of high intensity exercise targeting one body region on another body region. In a previous investigation, 5 min of heavy arm cranking at 30% of mean power output was performed prior to a lower body 30 s WAnT. It was reported that despite the arm cranking exercise elevating blood lactate (BLa⁻) levels to 11.0 ± 0.6 mM, no significant change in PP and MP was observed in the subsequent lower body 30 s WAnT (Bogdanis et al., 1994). Conversely, Halperin et al. (2014) found that elbow flexor force was significantly ($p < 0.05$) decreased following high intensity exercise of the knee extensor musculature. However, the relevance of the methodologies used in the above mentioned studies and their application to high intensity, intermittent exercise is questionable. The present investigation utilized repeated, maximal effort Wingate exercise using different body regions to more closely resemble high intensity sporting performance.

During the 30 s WAnT, PP output is indicative of instantaneous force output which relies on intramuscular stores of adenosine triphosphate (ATP) and phosphocreatine (PCr) (Baker et al., 2010). While the present investigation found that the lower body 30 s WAnT performance was not affected by prior upper body exercise, the upper body 30 s WAnT performance was significantly affected by prior lower body exercise. A possible explanation for these findings may be that upper body intramuscular ATP/PCr stores were used during the lower body 30 s WAnT as a result of gripping the handlebars (Baker et al., 2001). Consequently, the 1 min transition period between the lower and upper body 30 s WAnT testing equipment in the present investigation may not have been sufficient enough to allow the full replenishment of the upper body intramuscular ATP/PCr stores in preparation for the subsequent upper body 30 s

WAnT (Bogdanis et al., 1995).

The present investigation also found that both absolute (W) and relative ($W \cdot \text{kg}^{-1}$) MP output was significantly ($p < 0.01$) lower for the upper body 30 s WAnT when it was performed following a lower body 30 s WAnT. A plausible explanation for these findings may be attributed to the difference in energy system contributions between the upper and lower body 30 s WAnT. While the present investigation did not directly examine energy system contributions during the WAnTs, our laboratory had previously found that the anaerobic lactic energy system contributed over 60% of the energy requirements during the upper body 30 s WAnT, compared to less than 50% of the energy requirements during the lower body 30 s WAnT (Harvey et al., 2015). Similar contributions have been reported elsewhere for both the upper (Lovell et al., 2013) and lower body (Beneke et al., 2002; Granier et al., 1995; Harvey et al., 2015) WAnTs. Consequently the lower MP output observed during the subsequent upper body WAnT may be attributed to the increase in H^+ concentration from the lower body WAnT, impairing the glycolytic (anaerobic lactic) energy production for the subsequent upper body WAnT (Bogdanis et al., 1995). Furthermore, the gripping action experienced during the upper body WAnT may have occluded the blood flow, leading to a higher local H^+ concentration and a subsequent decrease in MP output (Bogdanis et al., 1995). However, during the lower body WAnT the cyclical motion may have allowed for a greater blood flow and therefore increased H^+ clearance and oxygen supply (Spriet et al., 1989). Consequently, no significant difference was found in MP output when the lower body WAnT was performed following the upper body WAnT. Additionally, the higher aerobic contribution of the lower body WAnT performance may have also reduced the reliance on the lower body glycolytic energy production and therefore, fatigue (Harvey et al., 2015).

As with all WAnTs, the resistance remains fixed for the duration of the sprint, therefore reductions in power are a result of changes in the number of revolutions performed. The results of the present investigation indicated that the RPMs for the upper body were significantly reduced following the lower body WAnT, while no significant differences were found between lower

body WAnT efforts. These changes may have occurred as a result of peripheral musculature fatigue in the upper body and the inability to regenerate ATP due to the reasons mentioned above. More recent evidence also indicates that the central nervous system may regulate muscle recruitment and limit performance during fatigue in short intermittent sprints (Billaut et al., 2013).

While this investigation provides the first examination of back-to-back WAnTs using different body regions, there were some limitations to be noted. The present investigation examined back-to-back WAnT performance in physically active males only. Although this provided important information, future investigations should examine this protocol with females due to significant differences in gender responses to high intensity exercise (Ben Ari et al., 1978; Murphy et al., 1984). Furthermore, athletes (both male and female) that are involved in sports requiring both upper and lower body performance should be examined to determine the effect of long term training on the physiological responses to back-to-back WAnT. Another limitation of this investigation is the lack of assessment of biochemical variables which may help to explain the results obtained. The present investigation did not examine the effect of two consecutive bouts of short duration, high intensity exercise on blood lactate or hydrogen ion (H⁺) concentrations which would provide an insight into the physiological state of the body after the upper and lower body exercise efforts. As such, future studies should measure these blood markers pre and post back-to-back exercise to provide a better understanding of the physiological strain from one body region and its effect on subsequent performance from another body region. Heart rate and oxygen debt variables should also be assessed and used to supplement biochemical data.

In summary, the present investigation found that while previous upper body sprint exercise did not significantly affect lower body

sprint exercise, previous lower body sprint exercise severely compromised subsequent upper body sprint performance. Furthermore, the maximum RPM for the upper body 30 s WAnT was significantly reduced following prior lower body sprint exercise. These findings have noteworthy consequences for sporting performance that involves both upper and lower body high intensity efforts. As such, future investigations should aim to further examine the mechanisms which cause fatigue in the upper and lower body musculature to help better understand why prior lower body exercise significantly impairs subsequent body exercise. Additionally, future investigations should also examine intermittent upper and lower body exercise to determine if similar results are found.

Practical Implications

- Training adaptations are dependent upon the specific type of training that is practiced. Therefore, athletes that participate in sports which require power and anaerobic capacity from both the upper and lower limbs should be mindful of the order of activities performed during training, as exercise order will significantly affect performance and ultimately the promotion of favourable training adaptations.
- Lower body high intensity exercise performance is not significantly affected by previous upper body efforts, therefore lower body testing and training can be performed before or after upper body training at no detriment to lower body power output.
- When looking to increase or assess upper body power and anaerobic capacity, coaches should be aware that upper body high intensity exercise performance will be significantly reduced following high intensity lower body efforts and should therefore be sequenced appropriately throughout training sessions.

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References

- Baker J, Gal J, Davies B, Bailey D, Morgan R. Power output of legs during high intensity cycle ergometry: Influence of hand grip. *J Sci Med Sport*, 2001; 4: 10-18
- Baker JS, McCormick MC, Robergs RA. Interaction among Skeletal Muscle Metabolic Energy Systems during Intense Exercise. *J Nutr Metab*, 2010; 2010: 905612
- Ben Ari E, Inbar O, Bar-Or O. The aerobic capacity and maximal anaerobic power of 30-to-40-year-old men and women. In Book G, Landry F, Orban W, editors. *Proceedings of the International Congress of Physical Activity Sciences*. Quebec; International Congress of Physical Activity Sciences, 427-433; 1978
- Beneke R, Pollmann C, Bleif I, Leithauser RM, Hutler M. How anaerobic is the Wingate Anaerobic Test for humans? *Eur J Appl Physiol*, 2002; 87: 388-392
- Bertuzzi RC, Franchini E, Kokubun E, Kiss MA. Energy system contributions in indoor rock climbing. *Eur J Appl Physiol*, 2007; 101: 293-300
- Billaut F, Kerris JP, Rodriguez RF, Martin DT, Gore CJ, Bishop DJ. Interaction of central and peripheral factors during repeated sprints at different levels of arterial O₂ saturation. *PLoS one*, 2013; 8: e77297
- Bogdanis GC. Effects of physical activity and inactivity on muscle fatigue. *Front Physiol*, 2012; 3: 142
- Bogdanis GC, Nevill ME, Boobis LH, Lakomy H. Contribution of phosphocreatine and aerobic metabolism to energy supply during repeated sprint exercise. *J Appl Physiol*, 1996; 80: 876-884
- Bogdanis GC, Nevill ME, Boobis LH, Lakomy H, Nevill AM. Recovery of power output and muscle metabolites following 30 s of maximal sprint cycling in man. *J Physiol*, 1995; 482: 467
- Bogdanis GC, Nevill ME, Lakomy HK. Effects of previous dynamic arm exercise on power output during repeated maximal sprint cycling. *J Sports Sci*, 1994; 12: 363-370
- Dotan R, Bar-Or O. Load optimization for the Wingate Anaerobic Test. *Eur J Appl Physiol Occup Physiol*, 1983; 51: 409-417
- Gabbett TJ. Influence of fatigue on tackling technique in rugby league players. *J Strength Cond Res*, 2008; 22: 625-632
- Granier P, Mercier B, Mercier J, Anselme F, Préfaut C. Aerobic and anaerobic contribution to Wingate test performance in sprint and middle-distance runners. *Eur J Appl Physiol*, 1995; 70: 58-65
- Halperin I, Aboodarda SJ, Behm DG. Knee extension fatigue attenuates repeated force production of the elbow flexors. *Eur J Sport Sci*, 2014; 14: 823-829
- Harvey L, Wiegand A, Solomon C, McLellan C, Lovell D. A comparison of upper and lower body energetics during high-intensity exercise. *J Sport Med Phys Fitness*, 2015; 55: 708-713
- Hawley JA, Williams MM. Relationship between Upper-Body Anaerobic Power and Freestyle Swimming Performance. *Int J Sports Med*, 1991; 12: 1-5
- Horswill C, Miller J, Scott J, Smith C, Welk G, Van Handel P. Anaerobic and aerobic power in arms and legs of elite senior wrestlers. *Int J Sports Med*, 1992; 13: 558-561
- Horswill CA, Scott JR, Galea P. Comparison of maximum aerobic power, maximum anaerobic power, and skinfold thickness of elite and nonelite junior wrestlers. *Int J Sports Med*, 1989; 10: 165-168
- Inbar O, Bar-Or O, Skinner JS. *The Wingate Anaerobic Test*. Champaign, IL: Human Kinetics; 1996
- Jacobs PL, Mahoney ET, Johnson B. Reliability of arm Wingate Anaerobic Testing in persons with complete paraplegia. *J Spinal Cord Med*, 2003; 26: 141-144
- Kohler RM, Rundell KW, Evans TM, Levine AM. Peak power during repeated wingate trials: implications for testing. *J Strength Cond Res*, 2010; 24: 370-374
- Kounalakis SN, Koskolou MD, Geladas ND. Oxygen saturation in the triceps brachii muscle during an arm Wingate test: the role of training and power output. *Res Sports Med*, 2009; 17: 171-181

- Lovell D, Kerr A, Wiegand A, Solomon C, Harvey L, McLellan C. The contribution of energy systems during the upper body Wingate anaerobic test. *Appl Physiol Nutr Metab*, 2013; 38: 216-219
- Lovell D, Mason D, Delphinus E, Eagles A, Shewring S, McLellan C. Does upper body strength and power influence upper body Wingate performance in men and women? *Int J Sports Med*, 2011; 32: 771-775
- Lovell D, Mason D, Delphinus E, McLellan C. Upper and lower body anaerobic performance of semi-elite Rugby League players. *J Sports Med Phys Fitness*, 2013; 53: 477-482
- Mahood NV, Kenefick RW, Kertzer R, Quinn TJ. Physiological determinants of cross-country ski racing performance. *Med Sci Sports Exerc*, 2001; 33: 1379-1384
- McLester JR, Green JM, Chouinard JL. Effects of standing vs. seated posture on repeated Wingate performance. *J Strength Cond Res*, 2004; 18: 816-820
- Metter EJ, Talbot LA, Schragger M, Conwit RA. Arm-cranking muscle power and arm isometric muscle strength are independent predictors of all-cause mortality in men. *J Appl Physiol*, 2004; 96: 814-821
- Murphy MM, Patton JF, Frederick FA. A comparison of anaerobic power capacity in males and females accounting for differences in thigh volume, body weight and lean body mass. *Med Sci Sports Exerc*, 1984; 16: 108
- Reiser RF, Maines JM, Eisenmann JC, Wilkinson JG. Standing and seated Wingate protocols in human cycling. A comparison of standard parameters. *Eur J Appl Physiol*, 2002; 88: 152-157
- Richmond SR, Whitman SA, Acree LS, Olson BD, Carper MJ, Godard MP. Power output in trained male and female cyclists during the Wingate test with increasing flywheel resistance. *J Exerc Physiol Online*, 2011; 14: 46-53
- Sheel AW, Seddon N, Knight A, McKenzie DC. Physiological responses to indoor rock-climbing and their relationship to maximal cycle ergometry. *Med Sci Sports Exerc*, 2003; 35: 1225-1231
- Sirotic AC, Knowles H, Catterick C, Coutts AJ. Positional match demands of professional rugby league competition. *J Strength Cond Res*, 2011; 25: 3076-3087
- Smith GA, Nelson RC, Feldman A, Rankinen JL. Analysis of V1 skating technique of Olympic cross-country skiers. *Int J Sport Biomech*, 1989; 5: 185-207
- Spriet L, Lindinger M, McKelvie R, Heigenhauser G, Jones N. Muscle glycogenolysis and H⁺ concentration during maximal intermittent cycling. *J Appl Physiol*, 1989; 66: 8-13
- Van Hall G, Jensen-Urstad M, Rosdahl H, Holmberg H-C, Saltin B, Calbet JA. Leg and arm lactate and substrate kinetics during exercise. *Am J Physiol Endocrinol Metab*, 2003; 284: E193-E205
- Watt KKO, Hopkins WG, Snow RJ. Reliability of performance in repeated sprint cycling tests. *J Sci Med Sport*, 2002; 5: 354-361

Corresponding author:**Leonie Harvey**

School of Health and Sport Sciences, Faculty of Science, Health & Education, University of the Sunshine Coast, 90 Sippy Downs Drive, Sippy Downs, Queensland, Australia 4556

Telephone: 61 4 8819 1276

Facsimile: 61 7 5430 4880

Email: lmh009@student.usc.edu.au