©Journal of Sports Science and Medicine (2003) **2,** 144-150
http://www.jssm.org

Research article

KINEMATIC DETERMINANTS OF EARLY ACCELERATION IN FIELD SPORT ATHLETES

Aron J. Murphy ✉, Robert G. Lockie and Aaron J. Coutts

Human Performance Laboratory, School of Leisure, Sport and Tourism, University of Technology, Sydney, Australia.

Received: 02 June 2003 / Accepted: 10 October 2003 / Published (online): 01 December 2003

ABSTRACT

Acceleration performance is important for field sport athletes that require a high level of repeat sprint ability. Although acceleration is widely trained for, there is little evidence outlining which kinematic factors delineate between good and poor acceleration. The aim of this study was to investigate the kinematic differences between individuals with fast and slow acceleration. Twenty field sport athletes were tested for sprint ability over the first three steps of a 15m sprint. Subjects were filmed at high speed to determine a range of lower body kinematic measures. For data analysis, subjects were then divided into relatively fast (n = 10) and slow (n = 10) groups based on their horizontal velocity. Groups were then compared across kinematic measures, including stride length and frequency, to determine whether they accounted for observed differences in sprint velocity. The results showed the fast group had significantly lower (~11-13%) left and right foot contact times ($p < .05$), and an increased stride frequency (~9%), as compared to the slow group. Knee extension was also significantly different between groups ($p < .05$). There was no difference found in stride length. It was concluded that those subjects who are relatively fast in early acceleration achieve this through reduced ground contact times resulting in an improved stride frequency. Training for improved acceleration should be directed towards using coaching instructions and drills that specifically train such movement adaptations.

KEY WORDS: Sprint performance, first step quickness, running speed

INTRODUCTION

Maximum running speed and acceleration are essential components in many different field sports including games such as rugby union, rugby league, soccer, Australian Rules football, and field hockey (Bangsbo et al., 1991; Deutsch et al., 1998; Meir et al., 2001). However, while maximum velocity is important in field sport performance, it is generally accepted that acceleration ability is of greater significance as players rarely cover large enough distances during sprint efforts to reach top speed (Reilly and Borrie, 1992; Reilly, 1997; Douge, 1988). Acceleration is physically defined as the rate of change in velocity. However, in a practical sense, particularly among applied sport scientists and coaches, acceleration ability is often referred to as sprint performance over smaller distances such as 5m or 10m, and assessed using sprint time or velocity. It is in this context that acceleration is used in the current study.

While kinematic studies have established that this high-intensity activity occurs relatively infrequently during competition (Reilly and Borrie, 1992; Meir et al., 2001), these bursts of maximal effort tend to be concentrated around crucial match actions such as making a break away from the opposition or a during tackle (Reilly, 1996; Rienzi et al., 2000; Meir et al., 2001). In particular, quickness over the first few steps of an sprint is viewed as being vitally important during a game (Penfold and Jenkins, 1996). While the kinematics of early acceleration has been analysed in track athletes using block starts (Merni et al., 1992), very little research exists specifically examining the most effective training modalities for sprint acceleration, particularly early acceleration. Furthermore, many coaching and training methods for improving acceleration in athletes have limited empirical support (Brown et al., 2000; Delecluse, 1997). For example, resisted sprint training has been suggested as an effective training method for improving sprint acceleration (Delecluse, 1997).

The aim of the current study was to determine what biomechanical factors separate field sport athletes with good early acceleration, from those with poor early acceleration. It was hypothesized that those athletes with better acceleration will demonstrate differences in key lower body kinematic variables, such as stride length, stride frequency and ground contact time, when compared to athletes with slower acceleration. It is anticipated that such data will be useful in the development of rational and effective acceleration sprint training programs, effective coaching feedback and provide a clearer focus for future research.

METHODS

Subjects

Twenty healthy men (age = 23.1 ± 3.7 y; mass = 82.6 ± 13.1 kg; height = 1.79 ± .06 m) volunteered to participate in this study. All subjects were currently active in various field sports, including rugby union, Australian rules football and soccer. The procedures used in this study were approved by the University's Human Ethics Committee, and informed consent was obtained prior to testing.

Testing procedures

All testing was conducted in an indoor gymnasium at the University of Technology, Sydney. Subjects were required to attend one testing session only. Prior to testing, and to ensure consistent results, each subject was led through an identical warm-up routine, lasting approximately 15 minutes, which included jogging, static and dynamic stretching, and sprints of increasing intensity.

In order to facilitate two-dimensional kinematic analysis during the sprint efforts, retro-reflective markers were attached to the right-hand side of the lower body prior to sprint testing. The landmarks were the: anterior superior iliac spine (hip_1); greater trochanter of the femur (hip_2); lateral epicondyle of the femur (knee); lateral malleolus of the fibula (ankle); and the fifth metatarsal (toe).

Following the warm-up, subjects completed two sprint trials over the assessment distance of 15m. Two successful sprint trials were considered completed when the 15m sprint times were within 2.5% of each other and these data were averaged to create a mean score. A standing start was used for the sprint tests as this was considered a more specific beginning position for these individuals. Subjects were positioned so that the right leg was the front and weight-bearing leg. Slight flexion of the hip and knee joints was required. The left leg was placed 30cm behind the heel of the front foot, with an extended hip and knee joint. The right arm was held behind the torso via extension of the shoulder joint with the elbow was flexed to approximately 90°. The left arm was extended in front of the torso again with the elbow flexed at 90°. Subjects were allowed to start in their own time, and rest periods of 1.5 min were allocated between trials. From the standing position, subjects were instructed to sprint maximally through to a marker at 15m. This study utilised an assessment distance of 15m for analysis because we were specifically interested in the kinematics of early acceleration, namely the first three steps of the sprint (two right foot toe-offs'), and wanted to ensure maximal effort through this portion of the sprint. In the current study, a step was defined as the difference in position of the takeoff foot at toe-off and the ground contact of the contralateral foot. A stride is defined as two concurrent steps.

Kinematic analysis

The descriptors for kinematic assessment were determined using both digital and videographic analysis recording at 100Hz. Both systems analysed the first three steps of the sprint where the first step was defined as the initial step (right foot toe-off), taken from the standing start position, resulting in a ground contact of the left foot. The second step occurred between left foot toe-off and right foot ground contact (heel contact) and so on for the third step. Raw data from both systems was filtered using a 4^{th} order low-pass Butterworth filter with a cut-off frequency of 12 Hz.

The joint kinematics and horizontal velocity of the sprint were determined using the Q-trac© System (Qualysis, Sävedalen, Sweden) which provided digital imagery of the markers, obtained via 2 infra-red cameras positioned 5m apart, and 8m perpendicular to the plane of motion. This system uses dual cameras for 2 dimensional kinematic analysis. The field of view was adjusted such that all markers were clearly recorded by both infra-red cameras during the first three steps. The marker on the anterior superior iliac spine (Hip_1) was used to measure horizontal hip velocity, and this velocity was used to assess horizontal running speed, as a high horizontal hip velocity has been shown to relate to a good sprint performance (Mann and Herman, 1985). For the purpose of this study, linear hip velocity was measured at the instance of toe-off at the beginning of the third step. This point was chosen as it represented the culminating velocity (or acceleration performance) of the first two steps.

In addition, various hip and knee joint angular measures were determined for each step (Figure 1). Values for hip and knee extension were calculated at the instance of toe-off for the first and third steps (right foot toe-off). Joint range of motion (ROM) for the hip and knee were calculated using the difference between highest and lowest extension values during a step (steps 1 and 3). Average hip and knee angular velocities were calculated by dividing the ROM by the time taken to achieve that ROM (steps 1 and 3).

In addition to the infra-red system, a JVC-DV 9800 (JVC, Tokyo, Japan) high-speed video camera provided videographic data sampled at a rate of 100 Hz. This camera was positioned at a point 8m perpendicular to the plane of motion and 2.5m in from the start position. The data collected by this camera were used to assess stride length, stride frequency, and the step flight and contact times. Contact and flight times were calculated for both the left and right foot (steps 2 and 3). Stride length was calculated as the distance between toe-off of the right foot at the start of the sprint to the heel strike point of the right foot.

Data analysis

Descriptive statistics were calculated for all dependant variables. Following the sprint trials, subjects were split into a relatively fast (n = 10) and slow (n = 10) group for comparative analysis on the basis of horizontal hip velocity. An analysis of variance (ANOVA), was then used to determine whether there was a significant difference between dependent variables in the fast and slow groups. Although the classifications used (fast vs slow) were arbitrarily defined, they did involve subject groups that had achieved horizontal velocities that were significantly different from each other. As such, they served the purpose of distributing subjects into two distinct categories of relative sprint performance. Type 1 error was controlled using Bonferroni corrections on the two main comparisons. Two variables (stride length and stride frequency) were used as Bonferroni adjustments will generally be too conservative using multiple dependant test variables (Bland and Altman, 1995). A corrected significance level for all comparisons was set at .05/2 = .025. All *P* values presented are uncorrected. All statistical analyses were computed using the Statistics Package for Social Sciences (Version 10.0).

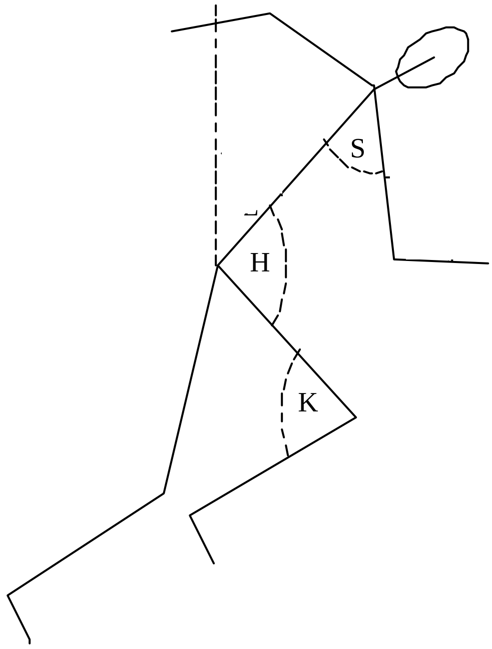


Figure 1. Joint angle conventions –right hand side of body only (H = hip, K = knee).

RESULTS

There were no differences between the relatively slow and fast group in terms of height, body mass or body mass index (Table 1).

Table 1. A comparison of kinematic variables for early acceleration in slow and fast sprinters. Data are means (SD).

Variable	Fast Group (n = 10)	Slow Group (n = 10)	p
Body Mass Index ($kg\cdot m^{-2}$)	25.1	25.4	.82
Horizontal Hip Velocity ($m\cdot s^{-1}$)	5.98 (.15)	5.39 (.23)	.00*
Stride Length (m)	2.09 (.15)	2.05 (.13)	.73
Stride Frequency (Hz)	1.82 (.12)	1.67 (.24)	.01*
Left Foot Contact Time (s)	.20 (.02)	.23 (.03)	.01*
Right Foot Contact Time (s)	.17 (.01)	.19 (.02)	.01*
Left Foot Flight Time (s)	.05 (.01)	.05 (.03)	.57
Right Foot Flight Time (s)	.06 (.01)	.06 (.02	.52

* Significant difference between the groups.

Table 2. Kinematic joint variables for early acceleration. Data are means (SD).

Joint Variable	Fast Group (n = 10)	Slow Group (n = 10)	p
1st Step (Right leg)			
Hip Extension (°)	141.1 (7.9)	143.1 (7.0)	.56
Knee Extension (°)	147.8 (9.8)	156.1 (9.5)	.07
Hip ROM (°)	52.5 (8.7)	56.0 (7.9)	.36
Knee ROM (°)	81.0 (8.9)	86.7 (18.1)	.38
Hip Ang. Vel ($° \cdot s^{-1}$)	224.8 (36.6)	240.8 (37.4)	.35
Knee Ang. Vel ($° \cdot s^{-1}$)	464.7 (31.9)	473.6 (77.2)	.74
3rd Step (Right leg)			
Hip Extension (°)	144.4 (6.3)	144.5 (5.3)	.99
Knee Extension (°)	142.3 (10.9)	153.7 (6.9)	.01*
Hip ROM (°)	47.8 (7.0)	48.0 (7.0)	.95
Knee ROM (°)	82.7 (10.4)	90.4 (14.2)	.18
Hip Ang. Vel ($° \cdot s^{-1}$)	232.7 (55.6)	238.6 (53.7)	.81
Knee Ang. Vel ($° \cdot s^{-1}$)	491.8 (70.5)	538.2 (79.8)	.19

Abbreviations: ROM = Range of motion, Ang. = Angle, Vel = Velocity.
* significant difference between the groups.

Horizontal hip velocity

Results showed that the relatively faster group had significantly ($p < .01$) greater horizontal hip velocity ($5.98 \pm .15$ $m \cdot s^{-1}$) than the slow group ($5.39 \pm .23$ $m \cdot s^{-1}$) (Table 1). This was expected, as significantly different linear hip velocities were used to delineate between good and poor acceleration performance over the first 3 steps. As such, we were confident that each group consisted of individuals who possessed significantly different levels of early acceleration ability.

Descriptive stride variables

There was no significant difference between the groups in stride length or flight times (Table 1). However, significant ($p < .05$) group differences were recorded for left and right foot contact times. The faster group had significantly lower times for both contacts (left foot contact = $.20 \pm .02$ s; right foot contact = $.17 \pm .02$ s) as compared to the slow group (left foot contact = $.23 \pm .03$ s; right foot contact = $.19 \pm .02$ s) (Table 1). In addition, stride frequency was significantly higher ($1.82 \pm .12$ Hz) in the faster group as compared to the slower group ($1.67 \pm .09$ Hz).

Joint kinematic variables

No significant differences between groups were recorded for any joint kinematics during the first step (Table 2), although right leg knee extension at toe-off approached significance ($p = .07$) with the fast group recording a ~5% smaller knee extension ($147.8 \pm 9.8°$ vs $156.1 \pm 9.5°$). Knee extension at toe-off for the third step (right leg) was significantly ($p < .05$) lower for the fast group ($142.3 \pm 10.9°$) as compared to the slow group ($153.7 \pm 6.9°$).

DISCUSSION

The aim of the present study was to determine whether specific kinematic factors separated field sport athletes with good and poor acceleration ability. Such information would provide clear direction for coaches and athletes in the development of training programs and the provision of appropriate feedback when training for improved acceleration. The results of this study clearly show that a number of kinematic variables differentiated individuals who were different in terms of their early acceleration abilities.

In field sports and in track events, an athlete's acceleration has been suggested to be an important determinant of performance (Mann and Herman, 1985; Penfold and Jenkins, 1996). In the current study, the horizontal hip velocity of the fast group ($5.98 \pm .15$ $m \cdot s^{-1}$) was significantly higher than the velocity recorded for the slow group ($5.39 \pm .23$ $m \cdot s^{-1}$). The values for both groups are similar to first stride instantaneous horizontal velocities reported in the literature (Merni et al., 1992) [$4.36 \pm .49$ $m \cdot s^{-1}$]; (Mero, 1988) [4.65 $m \cdot s^{-1}$]; (Schot and Knutzen, 1992) [4.87 $m \cdot s^{-1}$-5.61 $m \cdot s^{-1}$]), though the magnitude in the current study are slightly higher because they were calculated at toe-off of the third step.

Running velocity is a product of stride length and stride frequency. The present results showed no difference in stride length between the two groups (2.08 ± .15 m) despite the groups having significantly different acceleration ability. As such, it was expected that the deciding factor in the difference in horizontal hip velocity would be a disparity in stride frequency. Indeed, the results showed that those individuals with high acceleration ability had a 9% higher stride rate as compared to the relatively slow group (Table 1). Support for this finding was also seen in the flight time and contact time data. In the current study, the first ground contact (left foot) for the fast group lasted for .20 ± .02 s while the second contact time (right foot) was .17 ± .02 s (Table 1). Both of these values were significantly lower (15% and 12% for the left and right foot contacts respectively) than the corresponding values produced by the slow group (Table 1). Given that there was no difference in flight time (Table 1), the variation in contact times between the groups suitably accounts for the discrepancy in stride frequency.

Some authors have emphasized that a high stride frequency is important for fast acceleration in track sprints and in many field sports (Schroter, 1998; Brown et al., 2000). Our data provide empirical support to this suggestion. In particular, the present data shows that those athletes who are able to generate higher sprint velocities over short distances do so because of an improved stride frequency probably due to a reduced contact time. As such, we recommend that a focus on reduced ground contact time should be a key consideration of any sprint acceleration training program.

Recent evidence indicates that an increase in lower limb musculotendinous stiffness may allow athletes to achieve shorter ground contact times during running and sprinting. Spurrs et al. (2003) reported a 2.7% improvement in 3-km running time and a 7.8% increase in bounding performance after 6 weeks of plyometric training in trained distance runners. The authors also reported changes in ankle stiffness (11-15%) as a result of the training, and speculated that the increase in stiffness may have led to changes in stride kinematics resulting in improved running economy and bounding performance. Similar results were reported by Cornu et al. (1997) after 7 weeks plyometric training. Furthermore, recent data has reported similar significant relationships between leg stiffness measures and maximal sprint velocity (Chelly and Denis, 2001) (r = 0.68) and acceleration (Bret et al., 2002) (r = 0.59). Therefore, it is plausible to suggest that in the current study, those subjects in the fast group may have exhibited increased leg stiffness during early acceleration that led to the differences in contact time and stride frequency as compared to the relatively slow group. However, such a mechanism is purely speculative at this stage, as stiffness was not assessed in the current study. Future research is required to specifically investigate the relationship between musculotendinous stiffness and acceleration ability and kinematics.

The joint kinematic data presented in Table 2 may offer an alternate explanation, to the stiffness hypothesis, in accounting for the differences in acceleration ability between the groups. Knee extension values at toe-off for the first step approached significance in the current study, with the fast group being 6% smaller (p = .07). For the third step, subjects in the fast group had a significantly smaller knee extension (8%) than the slow group (Table 2). While there was no difference in hip extension in the current study, these findings are in contrast to suggestions by some authors that the leg should be fully extended during acceleration (Adelaar, 1986; van Ingen Schenau et al., 1994). In addition, research on maximal speed sprint kinematics has reported that knee extension is abbreviated at take-off, which is indicative of a reduction in joint extension (Mann and Hagy, 1980; Mann and Herman, 1985; Mann, 1986). The results in the current study suggest that in order to reduce ground contact time, subjects in the fast group may have abbreviated their knee extension at toe-off. This reduced range of movement potentially allows for a more rapid turnover of the lower limbs during acceleration, which may lead to a faster sprint performance. Whether the reduced knee extension at toe-off is a consequence of increased lower limb stiffness in the fast group or due to early activation of the hip flexors is currently unknown. Elucidation of the mechanism and potential benefits of abbreviated knee extension during acceleration should be the focus of future investigations.

CONCLUSION

The most significant finding from this study was that field sport athletes with good early acceleration exhibited higher stride frequencies, probably as a result of lower ground contact times. The data also showed that individuals with enhanced acceleration ability also tended to have an abbreviated right knee extension at toe-off at the first and third steps which contributed to reduced contact times. As such, we recommend that a focus on reduced ground contact time should be an important consideration of any sprint acceleration training program. It was suggested that increased lower limb musculotendinous stiffness might be an advantage by which reduced contact times can be achieved during sprint running. In addition, within a session, minimisation of ground contact time can be encouraged through specific instruction and feedback. We suggest that further research is needed to clarify some of the major issues raised in this paper, particularly the role of musculotendinous stiffness in early acceleration.

REFERENCES

Adelaar, R. S. (1986) The practical biomechanics of running. *American Journal of Sports Medicine* **14,** 497-500.

Bangsbo, J., Nørregaard, L. and Thosøe, F. (1991) Activity profile of competition soccer. *Canadian Journal of Sport Sciences* **16,** 110-116.

Bret, C., Rahmani, A., Dufour, A. B., Messonnier, L. and Lacour, J. R. (2002) Leg strength and stiffness as ability factors in 100 m sprint running. *Journal of Sports Medicine and Physical Fitness* **42,** 274-281.

Brown, L., Ferrigno, V. and Santana, J. (2000) *Training for Speed, Agility and Quickness,* Human Kinetics, Champaign, Illinois.

Chelly, S. M. and Denis, C. (2001) Leg power and hopping stiffness: relationship with sprint running performance. *Medicine and Science in Sports and Exercise* **33,** 326-333.

Cornu, C., Almeida Silveira, M. I. and Goubel, F. (1997) Influence of plyometric training on the mechanical impedance of the human ankle joint. *European Journal of Applied Physiology and Occupational Physiology* **76,** 282-288.

Delecluse, C. (1997) Influence of strength training on sprint running performance: Current findings and implications for training. *Sports Medicine* **24,** 147-156.

Deutsch, M. U., Maw, G. D., Jenkins, D. J. and Reaburn, P. R. J. (1998) Heart rate, blood lactate and kinematic data of elite colts (under-19) rugby union players during competition. *Journal of Sports Sciences* **16,** 561-570.

Douge, B. (1988) Football: the common threads between the games. In: *Science and Football*. Eds: Reilly, T., Lees, A., Davids, K. and Murphy, W. J. E & FN Spon, London, 3-19.

Mann, R. (1986) The biomechanical analysis of sprinters. *Track Technique* 3000-3003.

Mann, R. and Herman, J. (1985) Kinematic analysis of Olympic sprint performance: men's 200 meters. *International Journal of Sport Biomechanics* **1,** 151-162.

Mann, R. A. and Hagy, J. (1980) Biomechanics of walking, running, and sprinting. *American Journal of Sports Medicine* **8,** 345-350.

Meir, R., Colla, P. and Milligan, C. (2001) Impact of the 10-metre rule change on professional rugby league: implications for training. *Strength and Conditioning Journal* **23,** 42-46.

Merni, F., Cicchella, A., Bombardi, F., Ciacci, S., Magenti, L., Olmucci, S. and Coppini, L. (1992) Kinematic and dynamic analysis of sprint start. In: *ISBS Proceedings of the 10th Symposium of the International Society of Biomechanics in Sports*. Ed: Rodano, R. Edi-Ermes, Milan, 120-123.

Mero, A. (1988) Force-time characteristics and running velocity of male sprinters during the acceleration phase of sprinting. *Research Quarterly for Exercise and Sport* **59,** 94-98.

Penfold, L. and Jenkins, D. G. (1996) Training for speed. In: *Training for Speed and Endurance*. Eds: Reaburn, P. R. J. and Jenkins, D. G. Allen & Unwin, Sydney, 24-41.

Reilly, T. (1996) Motion analysis and physiological demands. In: *Science and Soccer*. Ed: Reilly, T. E & F.N. Spon, London, 65-81.

Reilly, T. (1997) Energetics of high-intensity exercise (soccer) with particular reference to fatigue. *Journal of Sports Sciences* **15,** 257-263.

Reilly, T. and Borrie, A. (1992) Physiology applied to field hockey. *Sports Medicine* **14,** 10-26.

Rienzi, E., Drust, B., Reilly, T., Carter, J. E. L. and Martin, A. (2000) Investigation of anthropometric and work-rate profiles of elite South American international soccer players. *Journal of Sports Medicine and Physical Fitness* **40,** 162-169.

Schot, P. K. and Knutzen, K. M. (1992) A biomechanical analysis of four sprint start positions. *Research Quarterly for Exercise and Sport* **63,** 137-147.

Schroter, G. (1998) Basics of the sprint start. *Modern Athlete and Coach* **36,** 23-26.

Spurrs, R. W., Murphy, A. J. and Watsford, M. L. (2003) The effect of plyometric training on distance running performance. *European Journal of Applied Physiology and Occupational Physiology* **89,** 1-7.

van Ingen Schenau, G. J., de Koning, J. J. and de Groot, G. (1994) Optimisation of sprinting performance in running, cycling and speed skating. *Sports Medicine* **17,** 259-275.

AUTHORS BIOGRAPHY:

Aron J. MURPHY

Employment

Senior Lecturer in Exercise and Sport Science, School of Leisure, Sport and Tourism, University of Technology, Sydney, Australia

Degrees

BHMS (Hons), Ph.D.

Research Interest

Strength and conditioning training adaptations, sprint training, ventilatory adaptations to exercise.

Email: aron.murphy@uts.edu.au

Robert G. LOCKIE

Employment:

PhD Candidate, University of Technology, Sydney, Australia

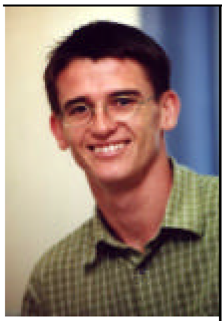
Degrees:

BA (Hons.), Human Movement.

Research Interest:

Acceleration in field sport athletes, biomechanics of sprinting and training methods for muscle hypertrophy.

E-mail: robert.g.lockie@uts.edu.au



Aaron J. COUTTS

Employment:
Lecturer in Exercise and Sport Science, School of Leisure, Sport and Tourism, University of Technology, Sydney, Australia

Degrees:
BSc.App.(HMS-ExMan), MHMSc, Ph.D.

Research Interest:
Physiology of prolonged, intermittent exercise; monitoring training fatigue and recovery in athletes.

Email: aaron.coutts@uts.edu.au

✉ **Aron Murphy, PhD**
School of Leisure, Sport and Tourism, University of Technology, Sydney, PO Box 222, Lindfield, NSW, 2070. Australia