

MUSCLE ACTIVATION AND FATIGUE DURING PROLONGED ENDURANCE CYCLING IN HOT AND COOL CONDITIONS – A COMPARISON OF ANALYTICAL METHODS

Angus Burnett^{1,2}, Chris Abbiss², Jonathon Green¹ and Paul Laursen²

¹School of Physiotherapy, Curtin University of Technology, Perth, Australia

²School of Exercise, Biomedical and Health Sciences, Edith Cowan University, Perth, Western Australia

The aim of this study was to compare analytical methods to quantify muscle activation and muscle fatigue in prolonged cycling. Six endurance-trained male cyclists performed a simulated 100 km time trial in hot (34 °C) and cool (10 °C) climates. During the time trial EMG from the vastus lateralis was measured in five 1 km sprints and variables indicative of muscle activation and muscle fatigue were measured via two different methods. The results from this study indicate that different methods of EMG analysis may change some findings in exercise-induced fatigue studies. Further, this study confirms the need for research in multi-disciplinary models of fatigue that consider biomechanical, physiological, biochemical and cognitive factors.

KEY WORDS: fatigue, cycling, methods, electromyography, climate

INTRODUCTION: In the time trial in road cycling, athletes individually ride a known given distance in the shortest possible time period. The ability to maintain a high power output during prolonged cycling is limited by the ability of the cyclist to resist fatigue. There has been considerable debate into whether fatigue is governed centrally (from the central nervous system to the muscle membrane) or peripherally (within the muscle membrane). Surface electromyography (sEMG) has been used as a tool to examine the within-muscle metabolic changes in a non-invasive manner. sEMG data can be examined in both the time (RMS or iEMG) or frequency (median frequency) domain. Exercise-induced fatigue is typically accompanied by increases in iEMG and there is a drop in the median frequency (Dolan et al., 1995). In the related literature, different methods have been used to quantify the level of muscle activation and muscle fatigue. Specifically, muscle activation in cycling has been quantified using iEMG (Hunter et al., 2003; Tucker et al., 2004) and RMS (Dolan et al., 1995) and fatigue has been examined using the change in the mean or median frequency (eg. Hausswirth et al., 2000) or the mean percentile frequency shift (MPFS) (eg. St Clair Gibson et al., 2001; Hunter et al., 2003). The conclusions of exercise-induced fatigue studies therefore, may be dependent upon the methods that are utilised. Thus, the purpose of this study was to examine different analysis methods to determine whether the choice of method used to analyse EMG data makes a difference in the conclusions generated. This study was conducted on cyclists performing a simulated 100 km cycle time trial in both hot (34 °C) and cool (10 °C) climates.

METHODS: Six endurance-trained male cyclists (mean \pm SD, age 32.2 ± 6.4 y; height 1.74 ± 0.10 m and mass 77.1 ± 8.7 kg) volunteered to perform in this study. Subjects had at least one year of cycling experience, and were cycling between 300 and 600 km per week at the time of the investigation. Subjects reported to the laboratory on four separate occasions, spaced at least seven days apart, and performed all tests at the same time of day. Subjects were required to abstain from heavy training 24 h prior to testing. The experimental procedure was approved by the Edith Cowan University Central Human Research Ethics Committee. $\dot{V}O_{2max}$ and peak power output were predetermined during an incremental exercise test to exhaustion using a Velotron cycle ergometer (RacerMate; Seattle, WA, USA) and a Medgraphics CPX Gas Analysis System (St. Paul, MN, USA). Following these tests, subjects performed three 100-km self-paced time-trials in thermal neutral (22.3 ± 0.6 °C, $56\% \pm 3\%$), hot (33.7 ± 0.5 °C; $44\% \pm 9\%$) and cool (10.5 ± 0.3 °C; $65\% \pm 4\%$) conditions. The first test was a familiarisation test followed by a randomised crossover design of the warm and cool conditions. Exactly five minutes following completion of a standardised warm-up,

subjects began the 100 km time trial with subjects aiming to complete the trial in the shortest possible time. In an attempt to replicate the dynamic characteristics of racing, subjects performed five all-out, 1 km sprints at 10, 32, 52, 72, & 99 km. Commencement of these sprints was displayed on a computer and subjects were instructed to complete the sprints in a seated position in the quickest time possible. Throughout these time-trials, power output, cycling speed, and performance times were recorded every second. Muscle activation of vastus lateralis was recorded via electromyography (EMG). A ME3000P8 data logger (Mega Electronics Ltd, Kuopio, Finland) was used to sample EMG at a frequency of 1000 Hz. The data logger was linked to a laptop PC via a fibre-optic cable. Silver/silver chloride disposable surface electrodes were fitted to the belly of each investigated muscle on the right leg. Inter-electrode distance was 20-mm and all electrodes were positioned and aligned as suggested by SENIAM. Maximal voluntary isometric contractions (MVIC's) were used for the normalisation of EMG data. MVIC's for the vastus lateralis were generated using a Cybex II-isokinetic dynamometer (Huntsville, AL). Subjects performed three MVICs and the largest value was selected for further analysis. A digital switch securely fitted to the bicycle frame was used to identify bottom dead centre (BDC) for the purposes of EMG data time normalisation. The switch allowed for the production of a digital signal (± 10 Volts) whenever the crank arm reached BDC. EMG data was collected for six seconds mid-way through the 1 km sprints in the hot and cool conditions. Raw EMG data was full-wave rectified, then smoothed with a zero lag low-pass fourth order Butterworth filter (cut-off frequency of 5 Hz) to produce a linear envelope (herewith termed iEMG for consistency with the related literature). Furthermore, RMS data was calculated with a 200 ms moving window. Once data were time normalised, an ensemble average for both methods of analysing EMG data from five continuous crank revolutions was used to reduce within-subject variability. All EMG data were amplitude normalised using the respective MVIC's. Data were calculated for BDC-BDC and TDC-BDC (concentric phase). For frequency domain data, the median frequency and the MPFS were calculated with respect to the 1 km sprint performed at the 10 km mark. Data were statistically analysed using a two-way ANOVA with two within-subject variables (condition and distance). Where a significant effect was found between conditions, post-hoc comparisons were made using Turkey's "honesty significant difference" HSD test for pairwise comparisons. Interactions were not examined in this study. All statistical tests were conducted using SPSS version 10.0 (Chicago, IL, USA). For all analyses, significance was accepted at $p < 0.05$.

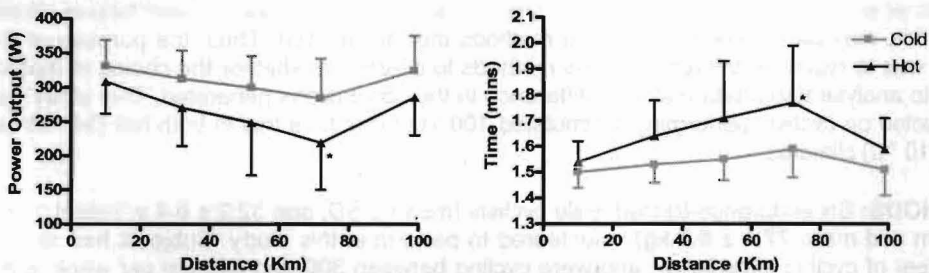


Figure 1 (A) Average Absolute Power Output during 1 km sprints and (B) 1 km performance times in hot and cool conditions. (* $p < 0.05$, distance main effect for the same environmental condition).

RESULTS: The Mean (\pm SD) $\dot{V}O_{2max}$ value for subjects in this study was 61.8 ± 8.3 ml.min⁻¹.kg⁻¹ and PPO was 341.9 ± 25.9 W. The overall performance times and average power output values for the hot and cool conditions were 180.8 ± 13.9 min and 168.1 ± 8.3 min and 259.3 ± 31.7 W and 219.5 ± 43.5 W respectively. Figure 1 shows the absolute power output values (Figure 1A) and performance times (Figure 1B) during the 1-km sprints in the hot and cool conditions. Significant differences were found at the 72 km mark when compared to the 10 km mark in the hot environmental condition for absolute power output

and time to complete the 1 km sprint. Figure 2 graphically displays the data for the 1 km sprints during the 100 km time trial for typical variables in the time (Figure 2A) and frequency (Figure 2B) domains. Further details of the entire data set are displayed in Tables 1 and 2.

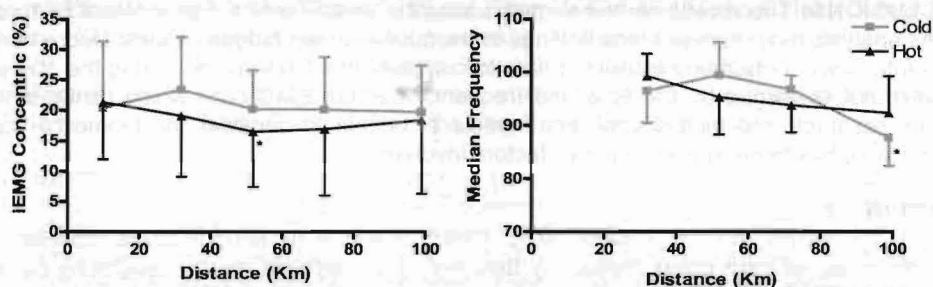


Figure 2 (A) iEMG (TDC-BDC) during the 1 km sprints and (B) median frequency relative to the first 1 km sprint (10 km) in hot and cool conditions.

(* $p < 0.05$, distance main effect for the same environmental condition).

Table 1 shows p -values for time domain related values generated in this study. When examining results that displayed statistical significance, from comparing the 52 km data to the 10 km data in the hot environmental condition, the p -values were similar using the iEMG and RMS methods between BDC-BDC (0.036 and 0.030 respectively). There were two instances where statistical significance was inconsistent between calculation methods although the p -values were close in value. These occurred at 52 km in the hot condition for iEMG and RMS (BDC-BDC) (p -values of 0.044 and 0.056 respectively) and at 72 km in the hot condition for iEMG and RMS (BDC-BDC) (p -values of 0.050 and 0.057).

Table 1 P-values for EMG variables measured in the time domain.

		Distance			
		32km	52km	72km	99km
iEMG	Cool	0.163	0.273	0.154	0.258
(BDC-BDC)	Hot	0.189	0.044*	0.050*	0.201
iEMG	Cool	0.220	0.497	0.274	0.528
(TDC-BDC)	Hot	0.315	0.036*	0.094	0.292
RMS	Cool	0.149	0.134	0.088	0.219
(BDC-BDC)	Hot	0.244	0.056	0.057	0.183
RMS	Cool	0.189	0.172	0.096	0.324
(TDC-BDC)	Hot	0.292	0.030*	0.080	0.252

(* $p < 0.05$, distance main effect for the same environmental condition).

Table 2 P-values for EMG variables measured in the frequency domain.

		Distance		
		52km	72km	99km
Median Frequency	Cool	0.155	0.914	0.040*
	Hot	0.303	0.064	0.095
MPFS	Cool	0.178	0.755	0.121
	Hot	0.272	0.131	0.094

(* $p < 0.05$, distance main effect for the same environmental condition).

Table 2 displays the significance values for the frequency domain data. The difference in p -value for significant results was more marked than those displayed for the time domain data. Specifically, the median frequency p -value was 0.040 for the 99 km mark in the cool condition whilst the significance value for MPFS data at the same point of the ride was 0.121. Decrements in absolute power output and increased time to complete the 1 km sprints during the 100 km ride in hot and cool conditions could not be explained by the time and frequency domain EMG data as no significant differences were found at the identical time points and

environment conditions. This confirms the need for multidisciplinary models of fatigue to be examined (Tucker et al., 2004).

CONCLUSIONS: The results from this methodological study confirm that different methods of EMG analysis may change some findings in exercise-induced fatigue studies. Decrements in absolute power output and increased time to complete the 1 km sprints during the 100 km ride were not explained by the time and frequency domain EMG data which confirms the need for research into multi-disciplinary models of fatigue to consider the biomechanical, physiological, biochemical and cognitive factors involved.

REFERENCES:

- Dolan, P., Mannion, A.F. & Adams, M.A. (1995). Fatigue of erector spine muscles: A quantitative assessment using "frequency banding" of the surface electromyography signal. *Spine*, 20, 149-159.
- Hauswirth, C., Brisswalter, J., Vallier, J.M., Smith, D. & Lepers, R. (2000). Evolution of electromyographic signal, running economy, and perceived exertion during different prolonged exercises. *International Journal of Sports Medicine*, 21, 429-436.
- Hunter, A.M., StClair-Gibson, A., Lambert, M.I., Nobbs, L. & Noakes, T. (2003). Effects of supramaximal exercise on the electromyographic signal. *British Journal of Sports Medicine*, 37, 296-299.
- StClairGibson, A., Schabort, E.J. & Noakes, T.D. (2001). Reduced neuromuscular activity and force generation during prolonged cycling. *American Journal of Physiology - Regulatory Integrative & Comparative Physiology*, 281, R187-R196.
- Tucker, R., Rauch, L., Harley, Y.X.R. & Noakes, T.D. (2004). Impaired exercise performance in the heat is associated with an anticipatory reduction in skeletal muscle recruitment. *Pflugers Archiv - European Journal of Physiology*, 448, 422-430.