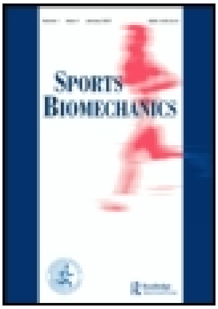

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Triathlon

Tamika Heiden [a] & Angus Burnett [a]

[a] School of Biomedical and Sports Science, Edith Cowan University, Perth, Western Australia

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The Effect of Cycling on Muscle Activation in the Running Leg of an Olympic Distance Triathlon

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TAMIKA HEIDEN and ANGUS BURNETT

ABSTRACT

The aim of this study was to determine the effect of prior cycling on EMG activity of selected lower leg muscles during running. Ten elite level triathletes underwent two testing sessions at race pace: a 40 km cycle followed by a 2 km run (CR) and a 10 km run followed by a 2 km run (RR). EMG data from selected lower limb muscles were collected at three sections of each run (0 km, 1 km and 2 km) for six strides using a portable data logger. Significant differences ($p < 0.05$) between condition were found for the level of activation (L_{act}) for biceps femoris (BF) during stance and vastus lateralis (VL) during flight and stance. Vastus medialis (VM) changed in L_{act}, during flight, between sections in the 2 km run. Furthermore, significant differences ($p < 0.05$) between condition were found for BF during stance and for rectus femoris (RF) and VM during flight. There was a significant difference ($p < 0.05$) in the duration of VL activation (D_{act}) across sections of the 2 km run. Findings from this investigation highlight changes in muscle function when changing from cycling to running and indicate a need to train specifically for the cycle to run transition. Such training may improve performance and reduce the risk of injury.

Keywords: electromyography, running, cycling, triathlon.

INTRODUCTION

Success in triathlon events is partly determined by the ability of an athlete to overcome difficulties in the change from one discipline to another. The combination of three disciplines in the one event requires a high volume of training. Anecdotal reports from triathletes highlight the transition from cycling to running as the more difficult of the two transitions in a triathlon event.

The cycle to run transition requires a change from non-weight bearing to weight bearing activity and requires the coordination of the leg muscles to be maintained whilst shifting from a predominantly concentric type of muscle action in cycling to the stretch-shortening activity used in running (Millet *et*

School of Biomedical and Sports Science
Edith Cowan University, Perth, Western Australia

al., 2000; Quigley and Richards, 1996). Hence it is proposed that the format of the triathlon is advantageous toward athletes who can run well immediately after the cycle discipline under fatigued conditions (Williams, 2000).

A number of studies have examined the biomechanics of running after cycling (Gottschall and Palmer, 2000; Hausswirth *et al.*, 1997; Millet, *et al.*, 2000; Millet and Vleck, 2000; Quigley and Richards, 1996; Witt, 1993). Commonly measured variables when examining running velocity include stride frequency and stride length. It should be noted that all these studies have been carried out in laboratory settings on treadmills. Wank *et al.* (1998) found a difference in stride length, stride frequency and EMG muscle activation between overground and treadmill running. Therefore, it would seem important to examine the effect of prior cycling on overground running in the field.

To the investigators' knowledge, few studies have examined the effect of prior cycling on the muscle activity of the legs in running using electromyography (EMG). Hausswirth *et al.* (2000) examined a prolonged run (2 hours and 15 minutes), a triathlon run (45 minute run after 40 km cycle) and an isolated run (45 minutes) measuring the EMG activity of the vastus lateralis. Results indicated that less muscle activation was evident during the triathlon run compared with the prolonged run. Furthermore, Witt (1993) found significant changes in activation of selected leg muscles after cycling. Specifically, activation began earlier in the stride and therefore activation durations were extended with the greatest variations in the vastus lateralis, tibialis anterior, and tensor fascia latae. However, there was no control for the effect of fatigue on EMG data which is known to alter the EMG signal (Oberg, 1995; Redfern, 1992; Winter, 1990).

The aim of this study was to determine the effect of prior cycling on EMG of leg muscles during running by comparing lower limb muscle activation in a 40 km cycle followed by a 2 km run (CR) and a 10 km run followed by a 2 km run (RR). Changes in the level of activation (L_{act}) and duration of activation (D_{act}) were examined over time (0, 1, and 2 km sections) and between the CR and RR conditions.

Two hypotheses were proposed for this study. The first was that the L_{act} and D_{act} of the sampled leg muscles during the CR when compared to the RR at three sections (0 km, 1 km, 2 km) would be significantly different. The second was that there would be a significant interaction between condition (CR and RR) and the three sections (0 km, 1 km, 2 km).

METHODS

Participants

Ten elite triathletes within the range of 20 to 35 years of age (mean age = 29.2 years) were invited to participate in this study. Selection was based on their performance at the Western Australian State Olympic distance championships. The maximum race time for these subjects was 2 hours and 5 minutes for an Olympic distance triathlon. Informed consent, in accordance with the Edith Cowan University Ethics guidelines was obtained from subjects prior to testing.

Data Collection

Data collection consisted of two separate tests conducted at race pace and undertaken a week apart in random order. These tests were: a 40 km ride followed by a 2 km run (CR) and a 10 km run followed by a 2 km run (RR). Since the level and influence of fatigue on EMG during different types of prolonged exercise has not yet been recognised, the length of the run in the RR condition was designed using energy expenditure calculations in an attempt to equate the energy expenditure of a 40 km cycle to that of a 10 km run (Hausswirth *et al.*, 2000).

All testing was carried out on a set course with the subjects using their own bikes. Subjects were instructed to perform a suitable warm-up prior to each testing session. The time of day and weather conditions were monitored for similarities, as were the cycle and run times of each test to reduce variability between subjects and trials. It is known that cadence alters the EMG activity of the lower limbs in cycling (Gregor *et al.*, 1991). Therefore, to reduce the effects of different cycling cadence between the subjects and its possible effect on muscle activation in running, subjects were instructed to reduce gears and increase cadence to maintain speed 1 km prior to transition from cycle to run.

Data was collected via a portable Mega Electronics ME3000 eight channel EMG data logger (Mega Electronics, Finland), which was held in a small waist-belt and strapped securely to the subjects. The data logger had a mass of 590 g. Only six channels were available for collection of EMG data and these were assigned to the vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF), biceps femoris (BF), lateral gastrocnemius (GS) and gluteus maximus (GM). Although tibialis anterior is known for its important contribution to both running and cycling, it could not be examined due to an insufficient number of channels in the data logger.

A single directional accelerometer was attached to the ankle of each subject to record heel strike and toe-off in the Y-axis (longitudinal axis of the lower leg) during each running stride. The method in which heel strike and toe-off were determined from the accelerometer is described elsewhere (Heiden and Burnett, 2003). Both EMG and acceleration data were sampled at 1000 Hz (EMG data had a 8-500 Hz bandwidth) over the duration of the 2 km run for both the RR and CR conditions. During the transition period prior to commencement of each 2 km run, the data logger was set to record continuously. The run was timed and typical triathlon speed was maintained by checking the subject's times to reach 1 km and 2 km.

To minimise variability between subjects and testing sessions, EMG electrode placement followed the surface EMG for a non-invasive assessment of muscles (SENIAM guidelines, Hermens *et al.*, 2000). Electrode positions were measured and marked on the skin with a waterproof marker for subsequent ease of positioning electrodes. These positions were then prepared by shaving and abrading the skin before cleaning the area with an alcohol swab. Once the skin was dry, bipolar 3M Red Dot Ag/AgCl surface electrodes with a diameter of 30 mm were adhered to the skin (20 mm inter-electrode distance) parallel to the muscle fibres over the respective muscle sites on each subject's right side

(Figure 1). Electrodes were secured to the skin with Beiersdorf Fixomull™ stretch tape to ensure that they remained attached to the skin during testing.

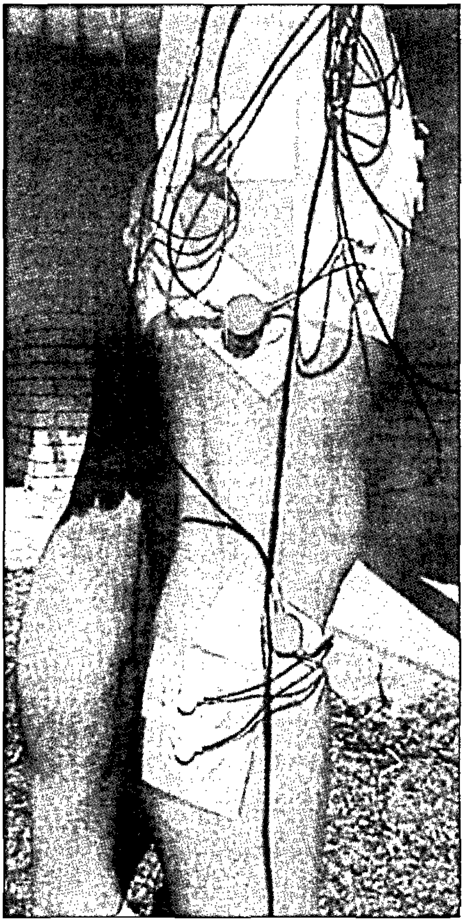

Figure 1 Electrode attachment and configuration.

Data Analysis

Three sections of six strides were identified using the times for heel strike and toe-off identified from the accelerometer data. These sections were the first six strides once race pace had been reached (0 km), the last six strides of the first kilometre (1 km) and the last six strides of the second kilometre before slowing occurred (2 km). The data was sectioned appropriately and the L_{act} and D_{act} were calculated as described below via a customised program written in LabVIEW V5.1 (National Instruments, Texas, USA).

Stride to Stride Repeatability of Lower Limb EMG

EMG data were full wave rectified and low pass filtered with a Butterworth digital filter (f_{cutoff} = 5Hz) to form a linear envelope from which ensemble averages were calculated for each muscle over each of the three sections of six strides. The measure of variation between strides for each subject was determined from the time normalised data via the coefficient of multiple correlation (CMC) (Kadaba *et al.*, 1989).

Level of Activation

To obtain the level of muscle activation of the raw EMG signals from each of the six channels of muscle activity were processed using a root mean square (RMS) with a 25 millisecond (ms) moving window (Nawoczenski and Ludewig, 1999). The swing and stance phases of the running stride were identified from the accelerometer data. Both the flight and stance phases were time normalised from 0 to 1000 using a cubic spline. RMS values were normalised to the average maximum value, of the six strides in each section, for each subject in each condition to allow for comparison of EMG data between subjects (MacIntosh *et al.*, 2000). The average RMS value for each section was computed for all subjects and expressed as a percentage of the individual's maximum RMS value for the stance and flight phases individually (MacIntosh *et al.*, 2000). Individual RMS values for the flight and stance phases were used to determine when the changes in the selected variables, L_{act} and D_{act}, were occurring.

Duration of Activation

The D_{act} for each muscle was determined from the ensemble average, described above by calculating a threshold (10% of maximum amplitude) to determine the onset and offset of muscle activation (Pinniger *et al.*, 2000). The maximum amplitude was determined for each subject by the maximum activation reached for each muscle within the eighteen measured strides in each condition. This threshold was applied to the ensemble average to determine the D_{act}. This value was calculated for each of the six muscles (RF, BF, VL, VM, GS and GM) and represented as a percentage of the stride phase (flight and stance).

Statistical Analysis

All statistical testing was carried out using the Statistical Package for Social Sciences (SPSS V10.0) software. Independent variables were time, the point during the run at which the measurement was taken, (with three levels i.e. the 0 km, 1 km, 2 km sections) and condition (with two levels i.e. CR and RR). The dependent variables were L_{act} and D_{act} for each of the six muscles measured for both stance and flight phases of the running stride were compared using a factorial ANOVA with two within-subject variables, as each subject participated in each condition. Due to the limitation of SPSS to conduct post-hoc analyses with repeated measures designs, post-hoc comparisons were performed using dependent t-tests. Differences were considered statistically significant at $p < 0.05$.

RESULTS

This section outlines the results obtained from the analysis of the VL, VM, BF, RF, GS, and GM during flight and stance for measurements taken at 0 km, 1 km and 2 km. The results are presented in three sections as follows: stride to stride repeatability of lower limb EMG, L_{act} and D_{act}.

Raw EMG profiles of all six muscles and accelerometer data for the Y-direction (acc) are shown in Figure 2. Examination of the raw EMG profiles was necessary to ensure data were artefact free. The raw accelerometer data were used to determine the points of heel strike and toe-off for data separation into flight and stance phases.

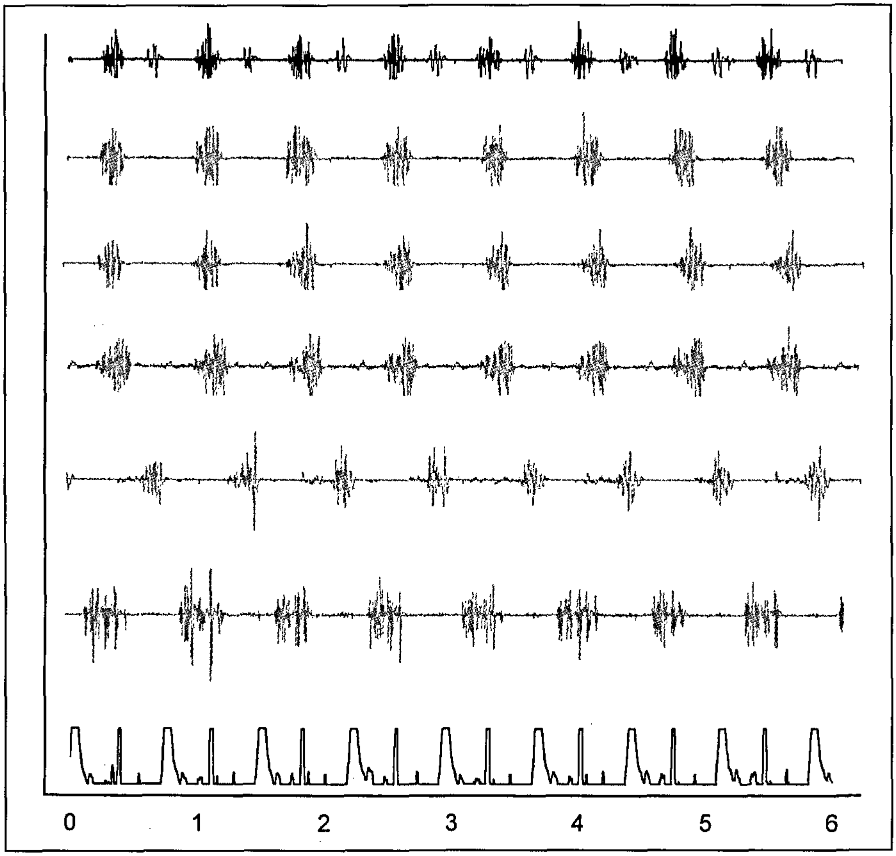

Figure 2 Raw EMG profiles and accelerometer signal (acc) from a representative subject for six muscles, RF (rectus femoris), VM (vastus medialis), VL (vastus lateralis), GS (gastrocnemius), GM (gluteus maximus) and BF (biceps femoris). The narrow spike on the acc pattern represents heel strike.

Stride to Stride Repeatability of Lower Limb EMG

The CMC measures indicated the similarity of the processed EMG waveforms between the six strides from each of the three measured sections for all subjects in this study. Similar waveforms have CMC values that are close to 1.0 (Kadaba *et al.*, 1989). The average CMC values for each muscle in CR and RR were between 0.862 and 0.988 as shown in Tables 1 and 2.

Table 1 Mean Coefficient of Multiple Correlation Results for the Cycle/Run Condition.

	0 km		1 km		2 km	
	Stance	*Flight*	*Stance*	*Flight*	*Stance*	*Flight*
RF	0.964	0.961	0.979	0.956	0.944	0.917
VM	0.949	0.972	0.968	0.968	0.975	0.986
BF	0.863	0.969	0.883	0.974	0.862	0.966
VL	0.975	0.982	0.962	0.986	0.974	0.982
GS	0.946	0.967	0.957	0.937	0.883	0.898
GM	0.932	0.944	0.904	0.933	0.926	0.880

Note: RF = Rectus Femoris, VM = Vastus Medialis, BF = Biceps Femoris, VL = Vastus Lateralis, GS = Gastrocnemius, GM = Gluteus Maximus

Table 2 Mean Coefficient of Multiple Correlation Results for the Run/Run Condition.

	0 km		1 km		2 km	
	Stance	*Flight*	*Stance*	*Flight*	*Stance*	*Flight*
RF	0.952	0.967	0.959	0.961	0.937	0.955
VM	0.959	0.984	0.961	0.985	0.967	0.979
BF	0.870	0.980	0.821	0.976	0.787	0.978
VL	0.972	0.986	0.979	0.988	0.982	0.990
GS	0.895	0.879	0.934	0.868	0.877	0.872
GM	0.910	0.954	0.900	0.964	0.885	0.957

Note: RF = Rectus Femoris, VM = Vastus Medialis, BF = Biceps Femoris, VL = Vastus Lateralis, GS = Gastrocnemius, GM = Gluteus Maximus

Level of Activation

The mean values with standard deviation (SD) for each muscle for L_{act} during flight and stance phases are represented in Figures 3 and 4 respectively. Statistical comparisons of RMS values for L_{act} in flight found significant differences ($p < 0.05$) between condition for the VL ($F_{1,9} = 7.98$) with 16.7% (SD = 2.4%) for CR and 15.7% (SD = 1.8%) for RR. VM displayed a significant difference ($p < 0.05$) across time ($F_{2,18} = 4.79$) and post-hoc analysis found the difference occurred between section one (0 km) 14.8% (SD = 2.1%) and section three (2 km) 13.9% (SD = 1.8%) indicating a reduction in the L_{act} of this muscle during flight as the run progressed.

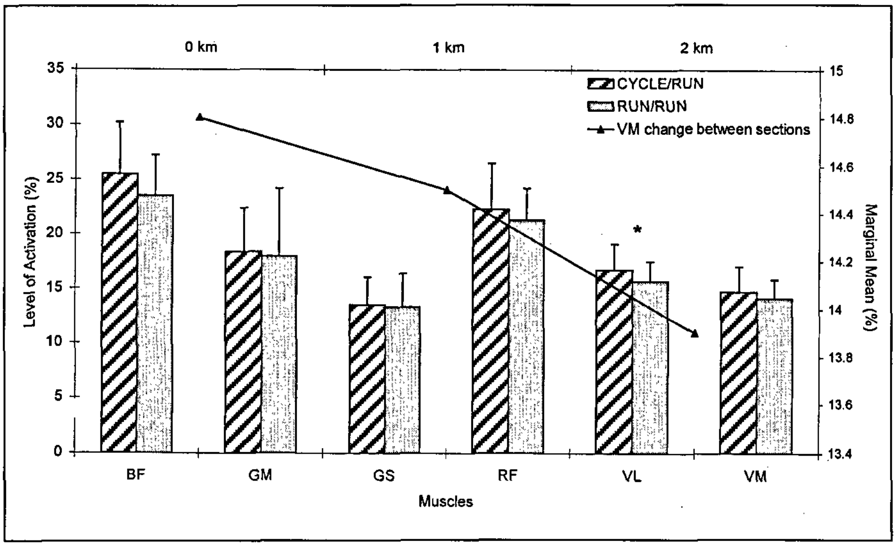

Figure 3 Comparison of the level of activation (L_{act}) between cycle/run and run/run during flight and change in L_{act} of VM between sections (1, 2, and 3 km). Significant findings are indicated by*.

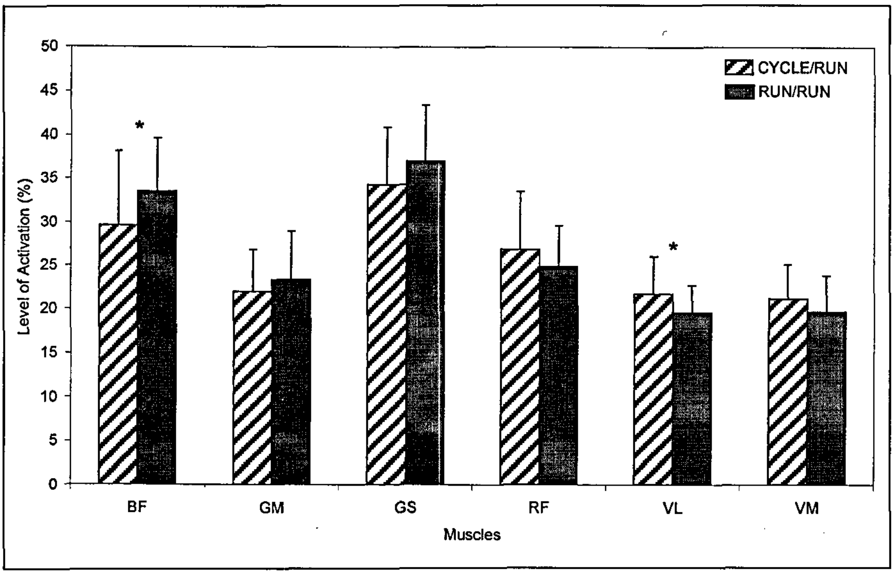

Figure 4 Comparison between conditions for the L_{act} during stance. Significant findings are indicated by*.

In the stance phase, two significant differences were found to occur between conditions. The first of these was in the BF ($F_{1,9}$ = 6.35) with lower L_{act} values of 29.6% (8.5) for CR than the 33.5% (SD = 6.1%) recorded for RR. The second was VL ($F_{1,9}$ = 7.33) with a greater L_{act} for CR 21.7% (SD = 4.3%) than for RR 19.6% (SD = 3.1%) .

Duration of Activation

The mean values with SD for each muscle during D_{act} for the flight and stance phases are shown in Figure 5. RF showed the highest D_{act} and the greatest variability among the sampled muscles during flight with 71.5% (SD = 31.5%) for CR and 64.7% (SD = 10.8%) for RR. Statistically significant differences ($p < 0.05$) were found for the main effect of condition for RF ($F_{1,9} = 6.22$) with increased D_{act} for CR 71.5% (SD = 31.5%) compared with RR 64.7% (SD = 10.8%). For VM there was a significant difference ($p < 0.05$) for the main effect ($F_{1,9} = 10.06$) again with increased D_{act} for the CR (27.1%; SD = 2.5%) compared to the RR (25.8%; SD = 2.0%).

Figure 5 presents the mean values with SD for D_{act} during stance of each muscle. The greatest difference among subjects was for BF with a significantly longer D_{act} for CR 78.3% (SD = 13.1%) than for RR 90.9% (SD = 11.7%). Furthermore, VL displayed a significant difference ($p < 0.05$) across time ($F_{2,18} = 4.71$). Post-hoc statistical analyses indicated the significant difference ($p < 0.05$) to have occurred between section two (1 km) with 57.0% (SD = 6.9%) and section three (2 km) with 59.4% (SD = 9.9%).

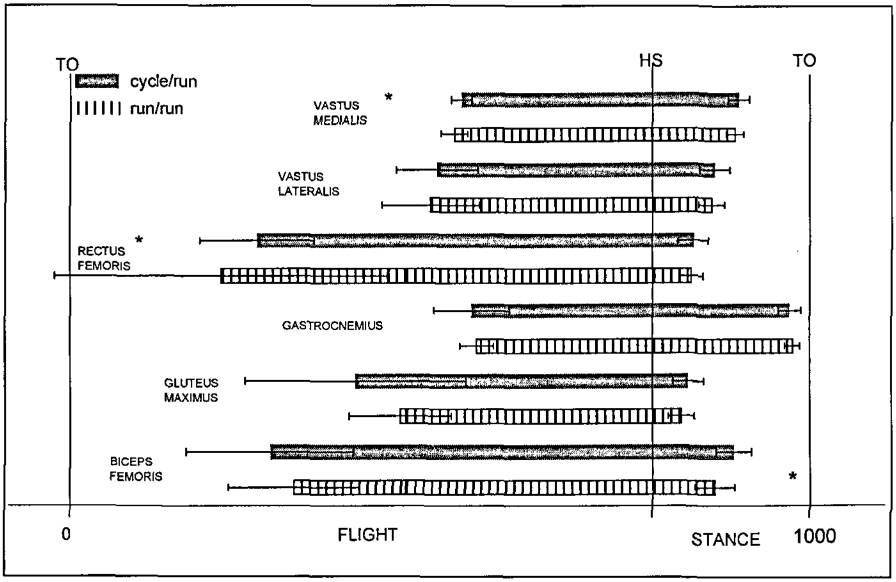

Figure 5 Duration of activation (D_{act}) for individual muscles during flight and stance. Significant findings are indicated by*.

DISCUSSION

Previous investigations of the biomechanics of the cycle to run transition have concentrated on the variables of stride length and stride frequency. However, there have been studies also of EMG changes in lower leg muscles during the running stride (Hausswirth *et al.*, 1997; Hausswirth *et al.*, 2000; Lepers *et al.*, 2001; Quigley *et al.*, 1996). The significant results found in this study are discussed in relation to kinematic and EMG findings from the abovementioned studies. The differences examined for this investigation are those measured in the first 2 km of running after transition where the greatest variations in the kinematics of running after cycling have been recorded (Gottschall *et al.*, 2000). The discussion is divided into stance and flight phases respectively to allow for better integration of the L_{act} and D_{act} variables for each muscle.

Stride to Stride Repeatability of Lower Limb EMG

Kadaba *et al.* (1989) reported within-day CMC values of 0.851 for GM, 0.883 for VL, 0.856 for RF, 0.871 for VM and 0.837 for BF in gait. The CMC values found in this study compare favourably with EMG repeatability measures found in gait and indicate a highly repeatable EMG pattern for all subjects across all muscles for both the flight and stance phases of the running stride.

Stance

During the stance phase of the running stride there were significant differences between the CR and RR conditions for BF and VL. There was also a significant change in the D_{act} between sections within the 2 km test period for VL. These significant findings are discussed in detail below.

Biceps Femoris: An increased L_{act} during stance in the RR condition was established for BF when compared to the CR condition. In running, BF has been found to display a maximum L_{act} of 52% during stance where its role is to initiate hip extension (Montgomery *et al.*, 1994). The L_{act} of the BF in cycling, in stark contrast to running, has been found to be quite low with a maximum activation level of 12% (Ericson *et al.*, 1985). It is thought that the low L_{act} experienced by the BF during cycling would allow this muscle to remain relatively fresh when moving into the run leg where its functional demands would be expected to be somewhat higher.

The higher demands placed on this muscle in the 10 km run when compared with a 40 km cycle, may have exhausted this muscle to a greater extent prior to the 2 km run. Consequently, its L_{act} would need to be higher to provide extension of the hip during stance. Pinniger *et al.* (2000) attributed a longer D_{act} and higher L_{act} in the hamstrings to occur in a fatigued state, due to a decreased capacity of the muscles to continue to produce the necessary contractions to maintain function. However, it should be noted however, that under fatigued conditions the amplitude of the EMG signal increases for a given task (Redfern, 1992) and therefore the L_{act} of the BF may have only increased due to the affect of fatigue on the signal.

Vastus Lateralis: The L_{act} of the VL during stance was found to be greater in the CR condition in this study. In running the VL contracts to stabilise the knee joint upon heel strike. According to Montgomery *et al.* (1994) it is during this initial impact that the VL has its maximum activation of 78%. The VL also plays a major role in cycling by providing propulsion with maximum activation levels of 50% (Ericson *et al.*, 1985).

The increased L_{act} of the VL in running after cycling may relate to the demands associated with knee stability when changing from a non-weight bearing cycling activity to a weight bearing running activity.

The D_{act} of the VL increased between section two (1 km) and section three (2 km) during stance, highlighting an increased demand on this muscle in providing stability of the knee joint throughout the 2 km run period. The VL plays a role in increasing joint stiffness by co-activating with the BF during stance (Kyrolainen *et al.*, 2001). The increased D_{act} of the VL may occur to provide improved stiffness as a precaution in stabilising the knee joint due to the change from non-weight bearing cycling to weight bearing running activity.

Alternatively the increased D_{act} of the VL may compensate for a more fatigued VM since VM has a slightly higher L_{act} in cycling (Ericson *et al.*, 1985). VL and VM work synergistically in stance to stabilise the knee joint (Montgomery *et al.*, 1994). However, in this investigation, only the D_{act} of the VL in stance was significantly different between conditions. Clements *et al.* (1999) found the highest incidence of injury in triathlon to occur on the lateral side of the knee in the running stage and hence the increased D_{act} of the VL could be further implicated with this finding.

Flight

During flight significant differences occurred between the CR and RR conditions for the VL, RF, and VM. Furthermore, VM had a significant change in the L_{act} between sections within the 2 km test period. These significant findings are discussed below.

Vastus Lateralis: VL had a significantly greater L_{act} during flight for the CR condition. During flight the VL is responsible for extending the knee prior to foot strike (Nilsson *et al.*, 1985). Maximum activation of the VL during flight in running (32%) has been found to occur in late swing as the knee is extending prior to foot strike (Montgomery *et al.*, 1994). It could be considered that extension of the knee may be more difficult when changing from the concentric muscle activation in cycling, where the knee is never fully extended, to the stretch shortening cycle in running where its role in flight is to extend the knee.

A study of the effects of cycling on running mechanics (Quigley *et al.*, 1996) recorded faster levels of knee extension in running after cycling, implying a greater role of the knee musculature during the flight phase and hence an increased L_{act} of the VL. It is thought that the BF, due to its role in controlling knee extension, would have also recorded a higher L_{act} if in fact faster levels of knee extension were the cause of this increase. Therefore, it is concluded that the increased L_{act} of the VL is more likely due to a change in the type of contraction.

Vastus Medialis: During the flight phase of running, the L_{act} of the VM was found to reduce between sections one (0 km) and three (2 km). This highlights the initial difficulties in the change from cycling to running that may possibly affect the extension of the leg due to changes in muscle contraction types. Further, an adaptation of the muscle to the changes in muscle contraction type, as time progressed, is highlighted by the subsequent decrease in the L_{act} of the VM during flight.

During flight VM also exhibited a greater D_{act} during CR compared with RR. During the flight phase of running, the VM functions to extend the leg in late swing in preparation for foot strike whilst exhibiting a maximum activation of 50% (Montgomery *et al.*, 1994). This muscle is also highly activated in cycling with a maximum activation level of 54% (Ericson *et al.*, 1985).

There are two possibilities for the extended D_{act} of VM during flight. First, the change from predominantly concentric contractions of the VM in cycling, where the knee joint is never fully extended, may impede its function in fully extending the knee at the end of flight during the run. Secondly, Hausswirth *et al.* (1997) found a greater degree of knee flexion to occur in the flight phase of running after cycling. As a result, a longer contraction of the VM may be required to extend the leg in preparation for foot strike. Although findings from Quigley *et al.* (1996) were not significant their results revealed slight increases in knee extension velocity in running after cycling, which may relate further to the increased D_{act} of VM. Alternatively the increase in knee extension velocity may also be related to the decreased eccentric activation of the BF possibly due to the decreased D_{act} in CR compared with RR.

Rectus Femoris: RF showed a significantly greater D_{act} during flight in CR to RR. During flight, the RF plays a role in both hip flexion and knee extension (Montgomery *et al.*, 1994). RF has a low peak activity of 12% during cycling where it functions as a knee extensor (Ericson *et al.*, 1985). Given that the VM also recorded an increase in the D_{act} in flight and that these two muscles are known to work synergistically it is thought that the increased D_{act} of the RF was due to its role in knee extension. If hip flexion was the cause of greater D_{act} then it is thought that the GM would have also shown some response to the CR condition.

Hausswirth *et al.* (1997) found a greater knee angle during the flight phase in running after cycling indicating greater knee flexion. The increased D_{act} of the RF may be due to this increase knee flexion requiring a longer contraction to extend the lower leg in time for foot strike. Alternatively, an increased flexion velocity of the knee joint would require RF to contract eccentrically to control hip extension whilst contracting concentrically to flex the hip also requiring a longer contraction time.

CONCLUSIONS AND IMPLICATIONS FOR COACHES

The findings from this investigation highlight changes associated with individual muscle function when changing from cycling to running. It was hypothesised that there would be significant differences in the L_{act} and D_{act} of the sampled leg muscles during running after cycling. This was found to be the case for the BF, VL, VM, and RF. However, the second hypothesis, that there would be a significant interaction between condition (CR and RR) and the three sections (0 km, 1 km, 2 km) was not confirmed.

There are several implications that can be drawn from the results of this study. First, the change from concentric muscle activation in cycling to stretch shortening muscle activation in running, possibly due to a decreased ability of the VL and VM to extend the knee in the flight phase of running, highlights a need for specific training for the cycle to run transition (so called *brick training*). Specificity of training may allow the muscles to adapt efficiently to the transition between cycling and running without difficulties associated with the change in contraction type.

The reduced L_{act} of the VM during the 2 km run suggests that an adaptation to the transition between cycling and running occurs over time. Therefore, training for the initial transition period may allow the muscle to become accustomed to the activity to be undertaken and ultimately improve the overall performance. However, it should be noted that the subjects tested were of an elite level and their adaptation to the cycle to run transition could be different to that of novice triathletes.

The change from non-weight bearing cycling activity to weight bearing running activity influences activation levels of the VL and VM, which may affect stability of knee and be related to the apparent high incidence of knee injuries in triathletes.

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