CHANGES IN ANKLE ANGLE AND MUSCLE ACTIVATION DURING CYCLING TO FATIGUE

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The purpose of the present investigation was to examine ankle angle and corresponding muscle activation patterns changes while novice cyclists cycled to volitional exhaustion during a maximal oxygen consumption (VO2max) test. Ten subjects (5 male, 5 female) underwent a VO2max test while electromyographic (EMG) and kinematic analysis data were collected simultaneously. Analysis indicated that minimum ankle angle decreased significantly and the amplitude of the ankle angle increased significantly. In addition muscle activation patterns rotate clockwise around the pedal stroke as the test continued. The results found here could be fatigue induced or load induced. More research needs to be conducted to determine the cause of these changes.

KEY WORDS: cycling, fatigue, ankle angle.

INTRODUCTION: Muscular fatigue can be defined as a reduction in the maximal force able to be exerted by a muscle (Millet et al, 2003). Muscular fatigue in cycling has been studied extensively as has electromyography during cycling exercise. It has been previously concluded that fatigue can cause change in neural input to the muscle causing failure of the contractile mechanisms (Lepers et al, 2000). It has also been concluded that cyclists can learn to use a co-activation strategies to maintain power output during periods of high work. However, the level of co-activation decreases during fatigue suggesting a decrease in muscular coordination (Hautier et al, 2000). Changes in muscle activation and coordination can lead to changes in joint angles reducing the effectiveness of the force producing torque on the crank shaft. The purpose of the present investigation was to determine if ankle angle and corresponding muscle activation patterns changed while novice cyclists cycled to volitional exhaustion during a maximal oxygen consumption VO2max test.

METHODS: All measurements were conducted on ten novice cyclists, five male and five female. Participants were selected based on their age, gender, health status, cycling experience and willingness to participate. All participants must have ridden a minimum of 100 miles per week during the previous cycling season. Subjects were expected to be in good health and under forty years of age during the time of participation. Descriptive statistics of participants are shown in Table 1.

Table 1 The average values of age, height (m), body mass (kg), absolute maximal oxygen consumption (L/min), and relative maximal oxygen consumption (ml/kg/min).

	Age	Height (cm)	Body Mass (kg)	VO2max (L/min)	VO2max (ml/kg/min)
Male	21.8	1.778	73.792	3.904	53.27
Female	22	1.6764	68.974	2.742	39.927

The bike used in this experiment was a standard flywheel cycle ergometer (Monarch 828E, Stockholm Sweden). Subjects were allowed to use their own shoes and cleats. They were also allowed to adjust the handlebars and seat to match their normal riding position. The pedal crank shaft used was 175 mm in length. Oxygen consumption was measured using a Parvomedics metabolic cart. A high speed digital video camera recording sagittal plane motion at 60 frames per second, reflective markers, electromyography (EMG) electrodes and the SIMI motion analysis program were used for biomechanical analysis.

EMG electrodes were placed two cm apart on the muscle belly of each of the following muscle bodies: tibialis anterior, lateral head of gastrocnemius, vastus lateralis, biceps femoris and gluteus maximus. Reflective markers were fixed to the subject to aid in digitizing. The markers were placed on the cleft of the knee, the lateral maleolus of the fibula and the tip of the cyclists

riding shoe.
The maximal oxygen consumption (VO2max) test used was a test designed specifically for cyclists by Meyer, et al (1999). Each participant started cycling at 100W with a cadence of 80 rpm. The power was increased by 50W every 2 minutes until volitional exhaustion/fatigue occurred. EMG data was collected at the end of every other minute of cycling by Noraxon EMG systems and stored in the SIMI program. Kinematic video footage was collected and stored in the SIMI system at the end of every other minute of cycling. EMG data and video data were collected and stored simultaneously. Oxygen consumption data was collected every 15 seconds by the metabolic cart. Ending of the max test was determined by a) participant desire to stop, b) blood pressure of above 250/100, c) heart rate that exceeded 110% of the participant's age predicted maximum heart rate, d) a RER greater than 1.1, or e) failure of VO2 to increase with an increase in workload (ACSM guidelines, 2000).
Data was then analyzed using the SIMI digital motion analysis program. Each marker was tracked digitally throughout the video footage producing graphs showing joint angle as a function of time. EMG data was analyzed concurrently with the video footage to allow a further understanding of joint angles and muscle recruitment.

RESULTS: Measurements from the end of the second minute and the last measurement for each participant were analysed. From the first to last measurements there was no change in the maximum ankle angle. The minimum ankle angle decreased by an average of 10.7 degrees in the direction of dorsiflexion. The amplitude of the ankle angle increased on average 10.7 degrees. A paired t-test indicated that the differences in minimum angle and angle amplitude are significant ($p<0.05$). These differences are shown in Figure 1. In addition to a change of ankle angle, The difference in recruitment pattern between the first and last measurements during the test showed that the EMG activity rotated clockwise around the pedal stroke in the case of gastrocnemius lateralis and counterclockwise around the pedal stroke in the case of vastus lateralis. Although the absolute measure of these data may vary, the trend is similar among all participants.

DISCUSSION: In discussing the current results, it is important to remember that application of force on the pedal of the bicycle is important, however, if that force is not exerted in the correct direction it may not transfer to large propulsive forces at the bike's wheel (Cavanagh et al, 1978). Given that torque is the product of force, distance and the sine of the angle at which the force is applied, ankle angle produces insight into the angle at which force is applied to the pedal. It has been reported that force applied to the pedal is maximally effective when the ankle produces an angle that makes the toe of that foot produce a 45 degree angle to the horizontal (Cavanagh et al 1978). Half way between top dead center and bottom dead center (at 3 o'clock and 6 o'clock or 900 and 2700), the ankle should be producing a 90 degree angle to the horizontal. For metabolically efficient cycling, it is important that large forces are not applied in ways that will produce small turning effect (Cavanagh et al 1978).

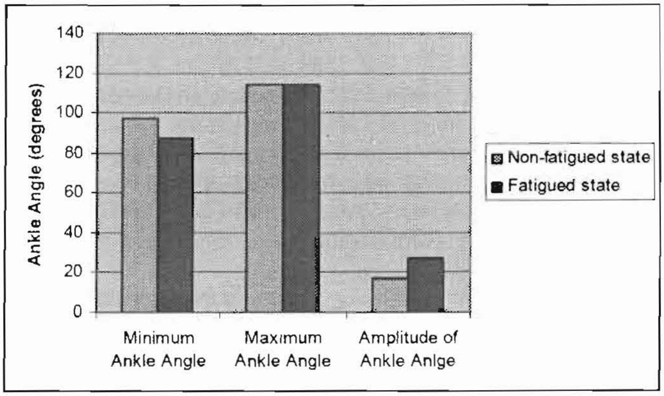

Figure 1: Values on maximum ankle angle, minimum ankle angle and amplitude of ankle angle during non-fatigued and fatigued states.

In this study the ankle angles were changing as the test proceeded indicating that either 1) stroke kinematics change according to work load, 2) stroke kinematics change with fatigue, or 3) stoke kinematics change with both load and fatigue. The changes in ankle angle were in the direction of dorsi flexion which puts the ankle at a more favorable angle for force production (Herzog et al. 1991). This would seem to be a natural adjustment to fatigue.
Changes in onset/offset times of the gastroc lateralis seem reasonable considering the ankle angle changes. Changes in onset/offset times of the gastroc lateralis and vastus medilis may indicate that increased cycling load requires not just more activation from the given muscles but rather alterations in muscle coordination. Because both increased load and fatigue were factors the role of fatigue in muscle activation patterns should also be considered.

CONCLUSION: The findings of this study indicate that significant differences occur in the minimum ankle angle and ankle angle amplitude. Changes in muscular activation patterns during a VO2max of novice cyclists were also documentd. Changes in ankle angle may lead to a decreased effectiveness of applied pedal force. Differences in ankle angles could have been caused by neuromuscular fatigue or differences in recruitment patterns. Results of this study provide new insight as to how fatigue and/or resistance load change pedal stroke effectiveness.

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