CARDIO-RESPIRATORY AND NEUROMUSCULAR RESPONSES TO MOTOCROSS RACE

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ABSTRACT

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Objectives - The primary aim of the present study was to examine physiological and neuromuscular responses during motocross racing. Furthermore, maximal isometric force levels of the upper and lower body were studied.

Methods - Seven Finnish A-level (group A) and five hobby-class (group H) motocross-riders performed a 30 minute riding test at a motocross track and muscle force and maximal oxygen uptake (VO_2max) tests in a laboratory. Variables describing cardio-respiratory strain were measured continuously during the riding and in the VO_2max tests. Muscle activity using surface EMG recording was recorded during the riding test and during the maximal isometric contractions.

Results – During the race the mean VO_2 reduced significantly in group A from 86 ± 10 % to 69 ± 6 % of the maximum. In group H the reduction occurred from 94 ± 25 % to 82 ± 20 %. The relative VO_2 between the maximum and the riding test correlated significantly with riding speed ($r = 0.70$, $p < 0.01$). Heart rate (HR) was maintained continuously at the level of 97 ± 7 % of its maximum in group A and at 98 ± 3 % in group H. During the ride, the mean blood lactate concentration was 4.0 ± 1.0 $mmol \cdot l^{-1}$ in group A but in group H it reduced from 5.7 ± 1.0 $mmol \cdot l^{-1}$ to 4.6 ± 0.7 $mmol \cdot l^{-1}$. Mean muscle activation of the lower body during riding varied between 24 – 38 % of its maximum in group A and between 40 – 45 % in group H. The activation of the upper body muscles varied between 62 – 116 % in group A and 68 – 178 % in group H of its maximum. The post-riding force measurements showed more significant ($p<0,05$) reductions in maximal voluntary contraction (MVC) of group H than MVC of group A. The absolute MVC measured before and after the riding experiment showed greatest reductions in hand grip forces.

Conclusions – Motocross causes great physical stress demanding on both skill and physical capacity of the rider. Physical stress occurs due to handling of the bike while receiving continuous impacts, while muscle actions are both dynamic and isometric placing demands in both aerobic and anaerobic metabolism. The data suggests that both the maximal capacity and the strain during the ride should be measured to analyze the true physiological demands of motocross ride including the recording of force levels before and after the ride to evaluate the neuromuscular fatigue due to the race.

Key words: motocross, riding, physiological stress, neuromuscular stress

CONTENTS

1 INTRODUCTION

Motocross is an extremely arduous, circuit-based cross-country race, completed on 125cc and 250cc two-stroke or 250cc, 450 or bigger four-stroke motorbikes. Grand Prix races demand about 2 hours of practice and qualifying on the preceding day of a race followed by practice and two 35 minutes + 2 laps races on the race day. Motocross is run over natural terrain, complete with jumps, holes, gullies, and uphill and downhill stretches that offer severe test of bike and rider. Track surface is usually hard clay or soft sand. The length of the motocross track varies between 1500-3000 meters. Top speed reaches over 100 $km \cdot h^{-1}$ but the average speed is not allowed to exceed 55 $km \cdot h^{-1}$.

It is usually hypothesized that the rider sits on the motorbike and the engine does all the work. However, the rider has to steer the motorbike weighing 85-110 kg over rough terrain and control it with considerable situational speed. The rider has to react rapidly to vigorous and sudden movements of the motorbike, which requires skill, endurance and force. Saltin (1975, 61) reported that physical demands and duration of motocross-race are similar to cross-country skiing on top level. The reasons of strain during a motocross race have been estimated to be body's complete isometric muscle work and psycho-emotional factors (Odaglia & Magnano 1979, Collins et al 1993).

Motocross research has mainly focused on injuries and risk factors of the sport. There are not too many studies about the strain during race. Muscle work has been mostly evaluated from a practical point of view. There are not any published data of riders' endurance or force capabilities either. (Collins et al 1993.) The aim of this study was to examine motocross-riders' cardio-respiratory and neuromuscular responses during the race. The responses were examined by comparing A-level and amateur riders with each other. The results can lead to a development of specific training methods for motocross.

2 CARDIO-RESPIRATORY RESPONSES DURING RACING

2.1 Heart rate

Saltin (1975, 61) measured the heart rate of four time world champion Heikki Mikkola for the 45 minute race with racing speed. After Mikkola got on the bike, his heart rate was 120 bpm and at the start of the race 110 bpm. During the first minute of riding his heart rate rose to 180 bpm and during the next minute to 195 bpm. After that the heart rate varied between 190-195 bpm until the end of the race. The heart rate may already reach a steady state during the first minute of the race. Also the starting level of the heart rate is higher at the beginning of a competition compared with the same situation in training (SML 1986-2003).

In a test situation the heart rate was 123 ± 16 bpm at the start (Konttinen 2004a, 25). In competitions the heart rate is 128 ± 19 bpm at the start. Differences between riders are quite considerable mainly due to psycho-emotional factors, because at that moment there is not much physical strain. (Odaglia & Magnano 1979, Von Lehmann et al 1982.) The heart rate does not rise any higher by prolonging the riding time. Instead of that it may decline at the end of the race due to fatigue. Alertness declines and the rider will not be able to ride at his/her maximal speed. The same tends to happen when a rider rides several races one after another. Average heart rate declines race after race. (SML 1986-2003.)

During the race the heart rate is continuously 90-100% of its maximum measured by a bicycle ergometer, but it can momentarily rise even above that. (Collins et al 1993). Similarly Konttinen (2004a, 25) reported that the heart rate during a 15 minute race was 192 ± 6 bpm, which was 95 ± 7 % of the maximal one measured by bicycle ergometer. During riding a steady state of heart rate was reached after two minutes. Odaglia and Magnano (1979) reported, however, that the heart rate reaches a steady state after five minutes of riding, which differs from Saltin (1975, 61), SML (1986-2003) and Konttinen (2004a, 25).

2.2 Oxygen consumption and lactate

According to Konttinen (2004a, 24) oxygen consumption during a 15 minute race is 32 ± 4 $ml \cdot kg^{-1} \cdot min^{-1}$ (2,5 ± 0,4 $l \cdot min^{-1}$) which is 71 ± 12 % of VO_2max measured by a bicycle ergometer. VO_2 reaches a steady state after two minutes and reduces slightly towards the end. (Konttinen 2004a, 24.) Odaglia and Magnano (1979) reported 2,1 $l \cdot min^{-1}$ for 250cc riders and 2,5 $l \cdot min^{-1}$ for 500cc riders respectively. VO_2 have also been estimated during racing based on lactate and heart rate levels by Von Lehmann et al (1982) who suggested that during racing VO_2 is comparable to 70-90% work of max VO_2.

Blood lactate has been measured during instant pit stops and after the race. Lactate levels have varied a lot between different studies. Konttinen (2004a, 25) measured 5,0 ± 2,0 $mmol \cdot l^{-1}$ a minute after a 15 minutes race and 13,4 ± 1,3 $mmol \cdot l^{-1}$ after maximal exhaustion by bicycle ergometer. Von Lehmann et al (1982) reported 6-8 $mmol \cdot l^{-1}$ lactate levels after 6 minutes riding, when the rest values were 1,5 ± 0,27 $mmol \cdot l^{-1}$. The average lactate level during and after racing by SML (1986-2003) test reports was 3,4 ± 1,3 $mmol \cdot l^{-1}$.

3 MUSCLE ACTIONS DURING RACING

It is suggested that motocross racing consists mainly of isometric muscle work (Odaglia & Magnano 1979). Oxygen consumption is 71 ± 12 % and heart rate 95 ± 7 % of maximum (Konttinen 2004a, 24-25). The same tendency has been discovered in rock climbing. Disproportion between oxygen consumption and heart rate in rock climbing (VO_2 50 % and heart rate 90 % of maximum) attributed to the fact that climbing requires the use of intermittent isometric contractions and the reliance of both aerobic and anaerobic metabolism (Sheel et al 2003).

There is also dynamic muscle work involvment during riding. When a motocross rider lands from a jump elbow, shoulder, knee and hip joint angles change and at the same time muscles around them activate. This shows that muscle work is also dynamic (Konttinen 2004b, 24). However, there are not any studies on muscle work during a motocross race, so the relation between isometric, concentric and eccentric muscle work remains unknown.

Knee, hip and elbow angles vary approximately from 80 to 170 degrees depending on the riding posture in different situations. Ankle joint's range of motion is limited because of firm boots. Ankle joint movements happen mainly when braking, shifting and receiving hits due to jumps and holes. Rider's movements are constant and rapid on the bike. A rider has to follow the movements of a bike which causes continuous change in muscle actions. Trunk muscles have an important role in maintaining balance. Forearm flexors work almost purely isometrically while gripping the handlebar. However, exceptions are made by the fingers which use clutch and front brake lever. Depending on the rider, usually either index, middle finger or both make almost continuous dynamic muscle work using clutch and front brake. However, the work done in each case is different. When the left hand fingers make rapid work pulling and releasing the clutch lever often, the right hand fingers make more powerful and slower movements pulling the front brake lever. (Diotto-Gerrard & Gerrard 1999.)

Konttinen (2004b, 26) examined a motocross jump on the flat surface. The average lengths of the jumps were 11,8 ± 1,0 m. The angle of the jump face was 19 degrees and height 1,0 m. Muscles activated in a certain order during landings from a jump. When jumping on a flat surface, the rear wheel hits the ground before the front wheel. The average vertical force relative to time that is directed to the rider-bike complex (187 ± 9 kg) was 12 474 N 21 ms after rear and 12 354 N 36 ms after the front wheel contact (approximately 86 ms after rear wheel contact.) (Figure 1). However, the force timing between subjects after the contact was not the same, so the average force which is not relative to time was 17 325 N. (Konttinen 2004b, 20.)

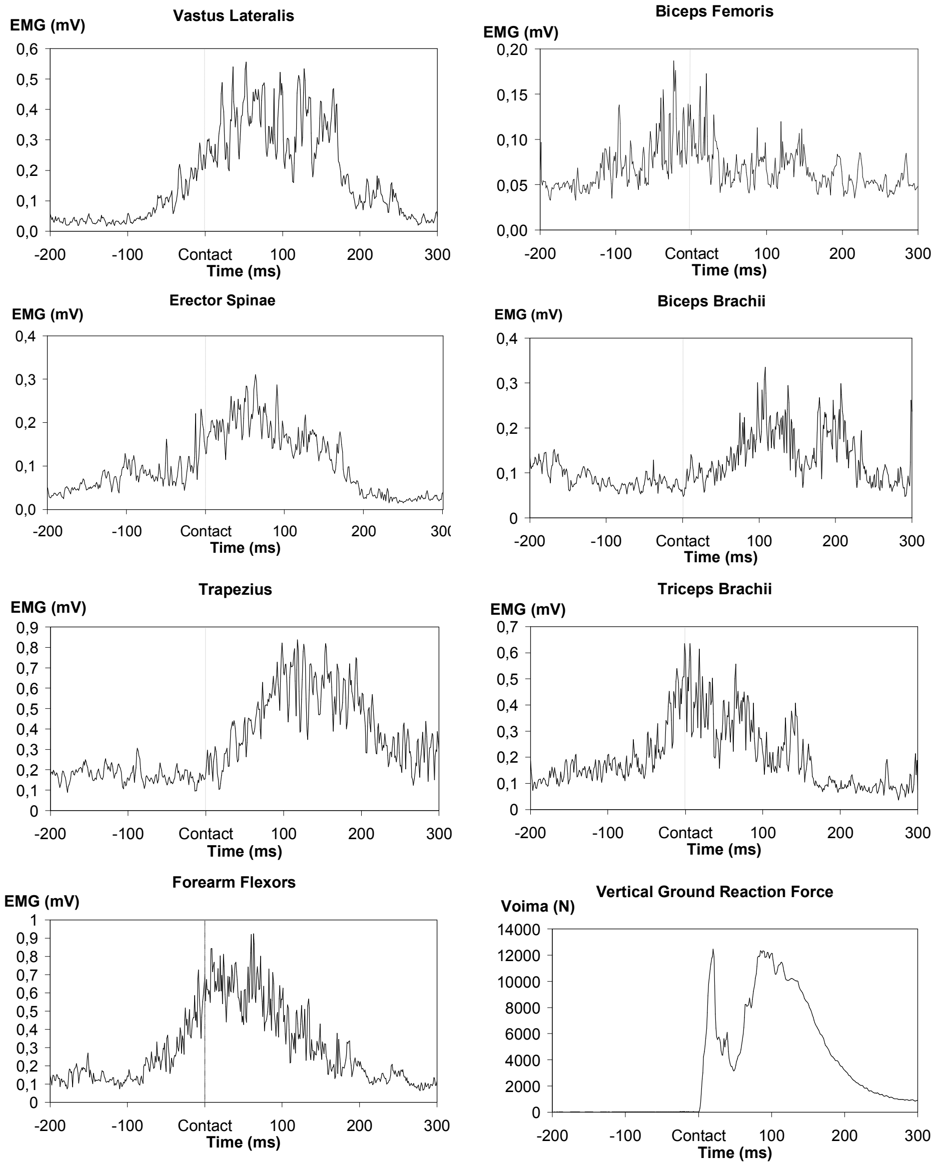

Figure 1. EMG-activation during landing of a motocross jump. (modified from Konttinen 2004b, 20 and 23).

First when the rear wheel touches the ground, thigh muscles absorb the force directed towards the rider. Activation of erector spinae reduces strain in arm musculature when the front wheel hits the ground approximately 50 ms after the rear wheel. At the same time it balances the whole body strain changing the angle of the trunk. The hand grip around the handlebar strengthens before the rear wheel contact. The grip, based on fore arm flexors' activation, is most powerful when the front wheel hits the ground. It may be assumed that the rear wheel contact causes greater strain in leg musculature than in the arms. It was suggested that vastus lateralis and erector spinae received the greatest hit due to the rear wheel contact. Triceps brachii pushes the front wheel towards the ground and after that biceps brachii and trapezius absorb the hit directed to arms through the handlebar. The wrist flexors must ensure that the hand grip force is adequate through the landing. There is co-operation between both lower and upper musculature and agonist-antagonist during landing. (Konttinen 2004b, 26.) Agonist-antagonist co-operation and different activation timing are consequences of specific training (Kyröläinen et al 1998).

4 PSYCHO-EMOTIONAL STRESS DURING RACING

Lactate is an indicator of physical strain and catecholamine excretion of psycho-emotional stress. It has been shown that there are major differences in catecholamine excretion and lactate levels between car racing and strenuous bicycle ergometer exercise. Catecholamine excretion is remarkably greater in car racing, which indicates greater psycho-emotional stress. Psycho-emotional stress raises heart rate during car racing. (Schwaberger 1987.)

Catecholamine excretion during motocross racing is substantially greater than during strenuous bicycle ergometer exercise. The average noradrenalin excretion in urine increases about four fold and adrenalin about ten fold over the resting excretion, which is significantly higher than during strenuous physical exercise. Psycho-emotional influence on heart rate may be considered as a minor factor on the grounds of lactate levels during racing. (Von Lehmann et al 1982.)

Psycho-emotional stress is greater for persons who are not physically fit. Endurance training reduces psycho-emotional stress and increases psychological capacity and stress tolerance. (Schwaberger 1987.) Also psychological factors are important, when endurance performance and the will to survive are in question. Psycho-emotional stress increases if an athlete does not have faith in her or his own physical performance.

Furthermore, this increases heart rate and oxygen consumption, and as a result there will be no success.

When an athlete believes in her or his physical capabilities and chances, there are not any significant alterations in cardio-vascular function. This has a positive effect on both physical and psychological performance. Physical capacity only is not enough in events which require also certain courage and will to survive in addition to physical performance (Taylor 1978.)

De Moja and De Moja (1986) examined the relation between anxiety and motocross performance of 32 local champions from all parts of Italy. They reported that anxiety is very common among athletes engaged in high level competitions. Risk factors in motocross have more effect on anxiety than in most of the other sport events. A rider has to be continuously ready to react to rapidly altering situations. Concentration must not be broken in any situation and the mind has to be focused on riding only. State-anxiety, which is represented by restlessness or fear for a certain moment or action, is common among less capable riders. The best riders have higher mean trait-anxiety, which is represented by concentration and high alertness. High-trait anxiety riders perform better probably because they are accustomed to processing data under high arousal. (De Moja & De Moja 1986.)

5 CARDIO-RESPIRATORY RESPONSES TO SUSTAINED SUBMAXIMAL ISOMETRIC ACTION

Heart rate responses to isometric muscle work are in relation to the loading level of its maximum. The higher the work of maximum, the more it raises the heart rate. Working with larger muscle groups, heart rate rise is greater as compared to small muscle groups. Isometric leg action raises heart rate more than arm work. However, isometric endurance, relative to muscle mass, is better in arm work. (Smolander et al 1998.)

When hand grip performance is 20 % of maximum, raises heart rate approximately by 20-25 bpm. The average time to sustain such force is 8-10 minutes (Figure 2). 40 % and 60 % hand grip forces raise heart rate approximately by 25-35 and by 35-45 bpm. The same relative force levels produced during knee extension by the quadriceps femoris muscle raise heart rate approximately 10 bpm higher as compared to forearm flexors (Figure 3). (Smolander et al 1998.) During back muscles' isometric contraction the heart rate rises linearly approximately up to 70 % of maximal heart rate before exhaustion (Sainio 1994, 34-38).

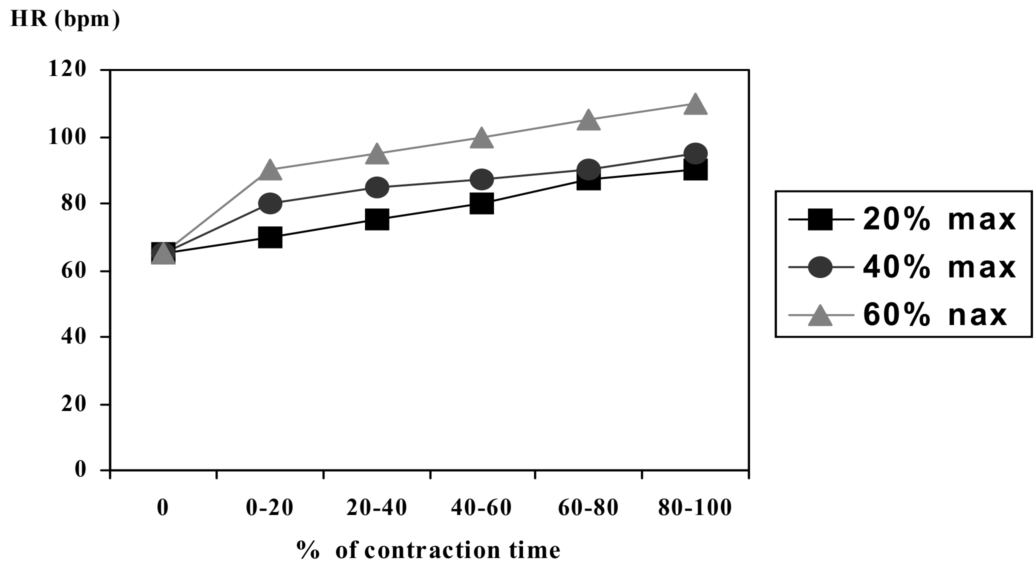

Figure 2. Heart rate responses to isometric hand grip and contraction time. (modified from Smolander et al 1998).

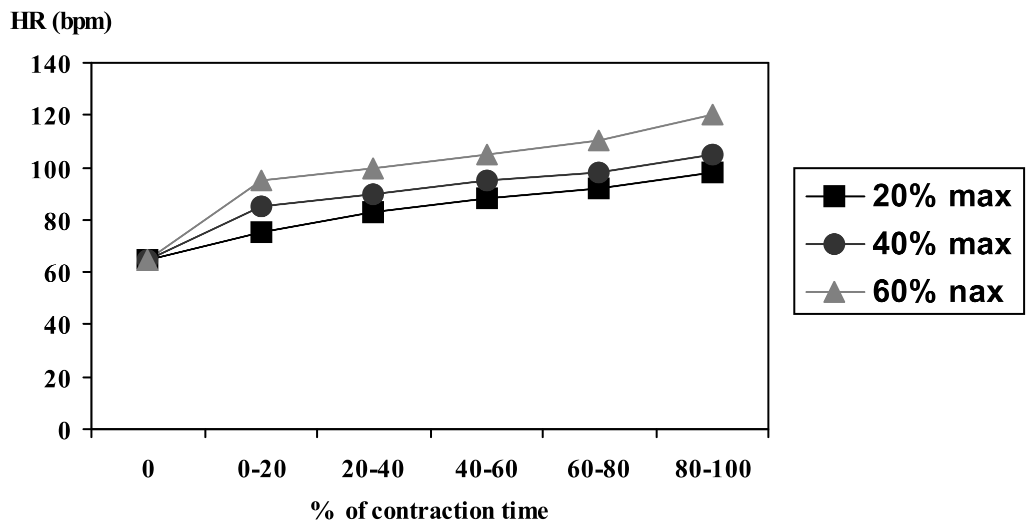

Figure 3. Heart rate responses to isometric leg extension and contraction time (modified from Smolander et al 1998).

In comparison to dynamic exercise, isometric exercise leads to relatively low increases in oxygen uptake and heart rate, while at the same time producing a prompt increase in mean arterial blood pressure. The pressure response is linearly related to intensity, activated muscle mass and duration of contraction. During a three-minute isometric dead lift at the 25 % load of maximum, oxygen consumption increases approximately by 6 $ml \cdot kg^{-1} \cdot min^{-1}$. At the 30 % load the oxygen consumption increase is 10 $ml \cdot kg^{-1} \cdot min^{-1}$ and at the 35 % load of maximum the increase is 12 $ml \cdot kg^{-1} \cdot min^{-1}$. At the 25 % of maximal voluntary contraction (MVC) ventilation increases by 15 $l \cdot min^{-1}$, at 30 % of MVC by 20 $l \cdot min^{-1}$ and at 35 % of MVC by 25 $l \cdot min^{-1}$. At 25 % of maximal isometric dead lift force blood lactate levels are over 2 $mmol \cdot l^{-1}$, at 30% they are over 3 $mmol \cdot l^{-1}$ and at 35 % approximately 4 $mmol \cdot l^{-1}$. (Sagiv et al 1999.)

Blood flow through forearm flexors increases by 20-30 % during isometric contraction and reaches the maximum already at 10-20 % of maximal hand grip force. However, blood flow, especially venous outflow is restricted by swollen muscles. Muscle oxygenation reduces significantly even at levels as low as 10 % of maximal contraction. (Cohen 2002.) Depending on the level of maximal contraction, oxygenation approximately halves during the first three minutes of isometric contraction. Increased blood flow increases oxygenation by over 20 %. It has been concluded that 20 % rise in blood flow at a low level of isometric contraction may hold oxygen consumption unchanged. (Joyner & Wieling 1993.)

6 EMG AND MUSCLE FORCE RESPONSES TO SUSTAINED SUBMAXIMAL ISOMETRIC ACTION

A decline in maximal force has been considered one of the most important signs of fatigue. It has been suggested that fatigue in voluntary contractions is most probably due to changes in the contractile properties of the muscle, the reduction in muscle activation by the central nervous system being of smaller importance. (Avela et al. 2001.)

Muscle fatigue during sustained submaximal isometric contraction influences the electrical and mechanical properties of the active motor units. The mechanical and electrical activities of motor units are altered ten minutes after fatiguing isometric exercise (repetitive cycles of 6s on and 4s rest) of the elbow flexors at 50 % MVC. In addition, after a ten-minute recovery from fatiguing exercise, some highly fatigable motor units might not be recruitable. (Esposito et al 1998.)

Throughout sustained intense isometric effort the EMG root mean square increases. Also the mean frequency of the power spectrum density distribution shifts toward lower frequencies (Esposito et al 1998). The linear increase in the EMG during exercise is dependent on changes in the muscle fibre action potential with a decrease in conduction velocity (Häkkinen & Komi 1983). The reasons for increasing EMG activity during exercise are: recruitment of additional motor units (Bigland-Ritchie & Woods 1984), increased firing frequency (Maton & Gamet 1989), synchronization and grouping of active motor units. (Krogh-Lund & Jorgensen 1993).

Muscle fatigue may be caused by a variety of reasons. Failure of force production may occur at the various sites along the pathway from the central nervous system through to the intramuscular contractile machinery. Some researchers have reported little or no central failure and others significant central activation failure during fatiguing exercise. It is suggested that central factors, which are not associated with altered peripheral excitability, play a significant, although modest role in the development of muscle fatigue during maximal voluntary contraction. The remainder is attributable to intramuscular factors. (Kent-Braun 1999.)

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The average time to sustain a 20 % hand grip force level in normal healthy men is 8 – 10 minutes. The endurance time reduces to 2 – 3 minutes while increasing the gripping force to 40 %. When the gripping force is 60 %, the average endurance time varies from 50 seconds to 1,5 minutes. The average endurance times during sustained isometric action in knee extension by quadriceps femoris are 2-6 minutes (20 % force of maximum), 1,5 – 2 minutes (40 %) and 40 s – 1 minute (60 %). (Smolander et al 1998.) Ferguson and Brown (1997) reported that rock climbers and sedentary subjects could sustain 40 % force of maximal isometric hand grip force 2 min 20 s ± 11 s and 2 min 2 s

± 14 s, respectively. The relative endurance is better with minor muscle mass. It is comparable, for example, between the upper and lower body and also between the same muscles between two subjects. (Smolander et al 1998.)

Back muscles or actually how they are used, differ from the arm and leg muscles. There are a number of muscles, which can compensate already fatigued muscles. For example, during back extension low back muscles become exhausted first and after that upper back muscles try to compensate exhausted low back muscles. Synergist muscles try to equalize the strain and after back muscles are exhausted, the exertion in hamstring and gluteus muscles increases. (Sainio 1994, 34-38.)

7 PURPOSE OF THE STUDY

The purpose of this study was to examine the physiological and neuromuscular stress of motocross riding. Neither neuromuscular or physiological fatigue due to motocross riding have been examined earlier.

Research Problems

1. What is physiological stress during motocross-riding like?

2. How do neuromuscular actions change during riding?

3. Is there a relation between riding speed and neuromuscular actions?

8 METHODS

8.1 Subjects

Subjects (n=12) who volunteered were divided into two groups according to their success level in motocross: 7 to group A and 5 to group H. Group A rode at Finnish A-level and group H riders were hobby-riders. The average age, height, body mass and BMI of group A riders was 23 ± 4 years and group H 28 ± 4 years, 180 ± 8 cm and 174 ± 8 cm, 72 ± 8 kg and 73 ± 15 kg, and BMI 22 ± 2 and 24 ± 3, respectively.

The subjects were explained the study protocol, risks and rights to determine any test at any time. The written consent was obtained. Every subject reported to be healthy and familiar with the benefits and disadvantages of the study. The subjects had an individual insurance for the case of accident. Also a third-party motor insurance existed for every motorcycle used in this study.

8.2 Overall design of the study

The riders performed a riding test at the motocross-track of Vantaa Speed Center, Vantaa, Finland, and VO_2 max test at the laboratory by Monark 839 E bicycle ergometer (Monark Exercise AB, Vansbro, Sweden) from the laboratory of the Department of Biology of Physical Activity, Jyväskylä, Finland. The ambient temperature varied between +5-10ºC but otherwise the weather was clear. The subjects rode with their own motorcycles (125 cc two-stroke and 250 cc and 450 cc four-stroke engines). Every other subject performing the riding test was a group A rider and every other group H rider to eliminate the differences due to changes in track conditions. The subjects rode approximately 30 minutes depending on what stage of the track they were when the time was up. EMG-activity and cardio-respiratory responses were recorded during the riding test. EMG-activity was recorded both during a jump and at a braking phase following a straight to a corner. EMG was triggered manually in every lap when the front wheel touched-off the ground for the jump. It was then recorded through an (approximately) 25 m jump, 50 m acceleration and 30 meter braking. (Figure 4). Expiratory gases were recorded continuously breath by breath as well as heart rate with five seconds averaged intervals. After each third (lasting approximately ten minutes), the riders pulled up and the finger tip blood sample was drawn for the lactate analyzes. Lap times were shown in every lap after the finish line with a pit board for the rider.

Laboratory assessments included pre and post-riding neuromuscular performance and VO_2max tests. The VO_2max test was performed one week after the riding test. Before the pre-riding measurements finger tip blood sample was drawn for the lactate analyzes. Electromyography (EMG) activity was recorded from five muscles: vastus lateralis (VL), vastus medialis (VM), biceps brachii (BB), triceps brachii (TB) and forearm flexors (FF). The EMG electrodes were placed according to Hermans et al (1999) on shaved, abraded clean skin. Isometric MVCs were recorded during leg extension with the knee angle of 107°, arm extension and flexion with elbow angle of 90° and hand grip. In addition the 30% MVC of leg extension and arm flexion was then remained stable for 15 seconds, while EMG activity was continuously recorded. The same protocol was then repeated in the post-riding measurements. A 5-minute warm up by bicycle ergometer was performed before the pre-riding measurements and a 15-minute warm up by riding was performed before the riding test. The reference riding was performed both sitting and standing on a flat hard sand surface, and EMG activity was recorded continuously.

The VO_2max test was performed using an incremental loading protocol with two minute stages at a natural pedalling rate of 60-100 rpm. Each subject began pedalling at a load of 50 W and the load was increased 30 W every two minutes until exhaustion. Expiratory gas exchange was recorded continuously utilizing a breath by breath method. The heart rate was recorded in every 5 s, while blood sample from a finger tip was drawn for lactate analysis at rest and at the end of the each loading.

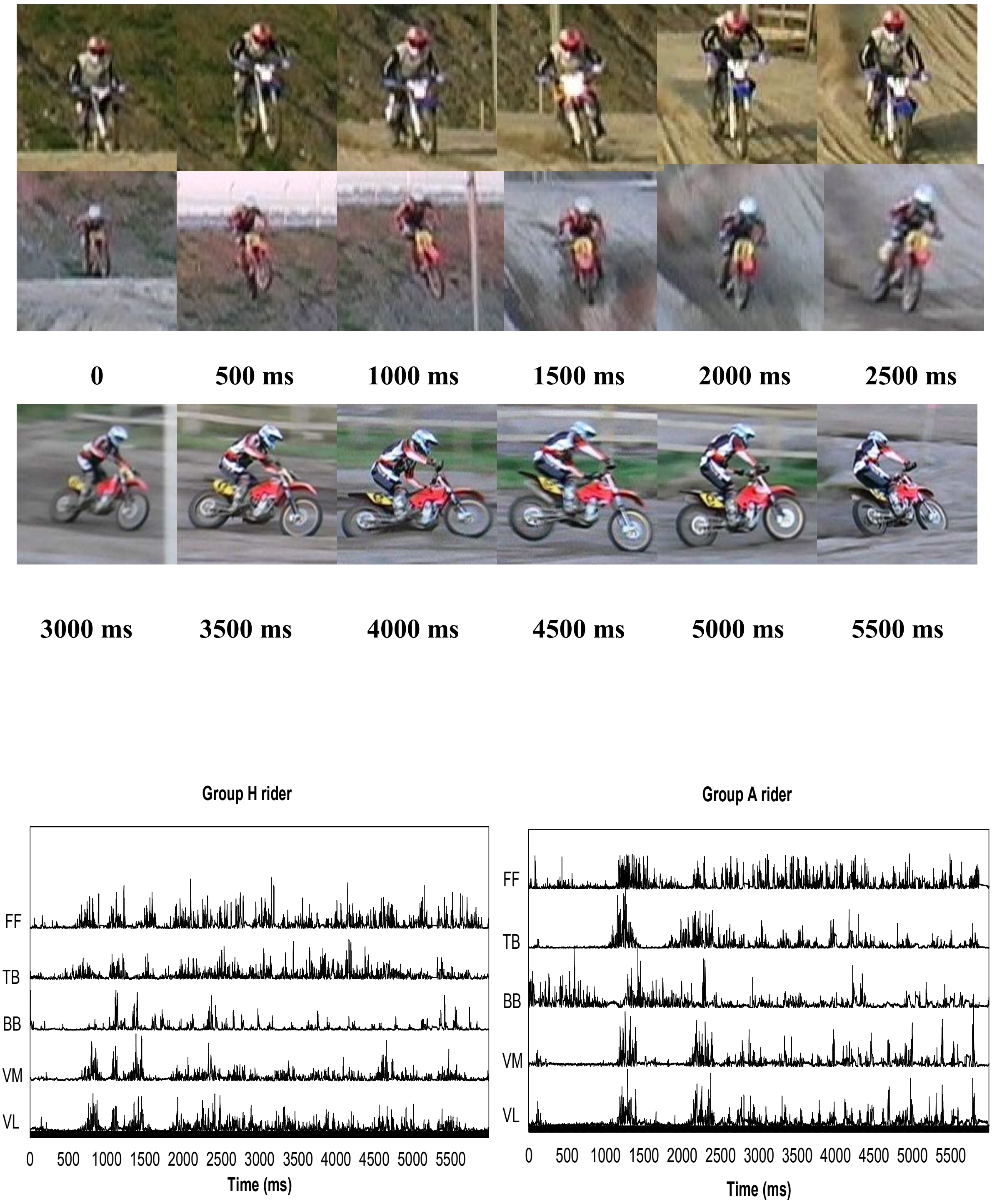


Figure 4. The different parts of landing and braking and rectified EMG data. Jumping pictures represents the difference of a jumping tecnique and timing of a group H rider (on top) and a group A rider (below).

8.3 Measurements and analysis

Oxygen consumption (VO_2), ventilation (VE), respiration frequency (RF), heart rate (HR), blood lactate (LA), energy expenditure ($EE{\cdot}kg^{-1}$ and METs) and maximal voluntary contraction of the left (MVCl) and right (MVCr) hand grip muscles were measured. Energy requirements were assessed by indirect spirometry. Respiratory variables were measured with Cosmed $K4b_2$ gas exchange analyzer (Cosmed srl, Rome, Italy). Heart rate was recorded every five seconds with Polar S810i heart rate monitor (Polar Electro Oy, Kempele, Finland). Finger tip blood samples were analyzed by Lactate Pro analyzer (Arcray Inc, Kioto, Japani). Racing time was recorded with a stopwatch every time the front wheel crossed the finish line.

Leg extension dynamometer (Department of Biology of Physical Activity, University of Jyväskylä, Jyväskylä, Finland) and David 200 (David Finland Oy, Helsinki, Finland) were used to measure leg and arm musculature MVC. A hand grip gauge (Department of Biology of Physical Activity, University of Jyväskylä, Jyväskylä, Finland) was used to measure maximal voluntary contraction. The handholds were 2.5 cm apart of each other.

EMG activity was recorded telemetrically (Glonner, München, Germany) with bipolar silver chloride surface electrodes (University of Jyväskylä, Jyväskylä, Finland). The interelectrode distance was 20 mm. The EMG signal amplification was 200 (Glonner Biomes 2000; bandwith 3-360 Hz per 3 dB^{-1}). In jumping, the EMG activities were full-wave rectified and integrated from 500ms to 3000ms after the front wheel touched-off the ground for the jump. The same braking phase from the videotape was selected for each subject for the analysis of EMG.

Respiratory variables, energy expenditure and heart rate during the riding test were defined as a mean of 30 seconds after the steady state was reached. The measured variables were then compared between the groups and individually with riding speed.

8.4 Statistical analysis

The data were presented as means and standard deviation (SD). The relationships between different variables were examined by the regression analysis and Pearson's correlation coefficient. T-test and correlation coefficient test were used to test the statistical significances. A value of $p<0.05$ was used to express the levels of significances.

9 RESULTS

9.1 Riding lap times

Each subject could ride with their own maximal speed without having significant reductions in lap times at the end of the experiment. The group A riders were significantly (p<0.01) faster than group H riders. The average lap time of groups A and H were 2 min and 2min 15 s, respectively. (Figure 4).

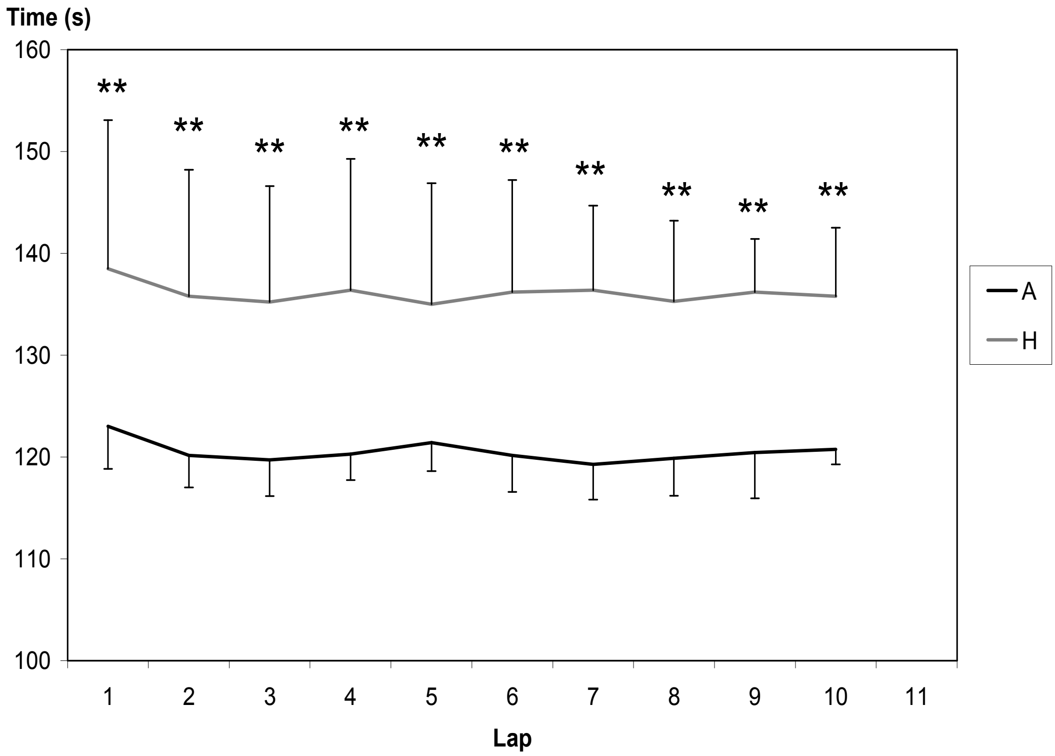


Figure 4. The average lap times of groups A and H. Group A riders were very significantly faster than group H riders. * represents the difference between the groups in each lap. (**p<0.01).

9.2 Changes in force production

Both groups could achieve similar force levels in the pre-riding measurements. The only significant (p<0,05) difference observed was a lower maximal voluntary contraction (MVC) of the left hand gripping in group H. Maximal voluntary contraction of both left

(MVCl) and right (MVCr) hand gripping force dropped significantly due to the riding. The reduction was greater in group H (MVCl 28 ± 13 %, MVCr 32±20) than in group A (MVCl 10 ± 17 %, MVCr 13 ± 14 %). (Figure 5). The force-time curve of the hand gripping shifted due to the riding to the lower level ($p<0.01$) already at the beginning of the force production in both groups. (Figure 6). The maximal RFD remained, however, unchanged among both groups.

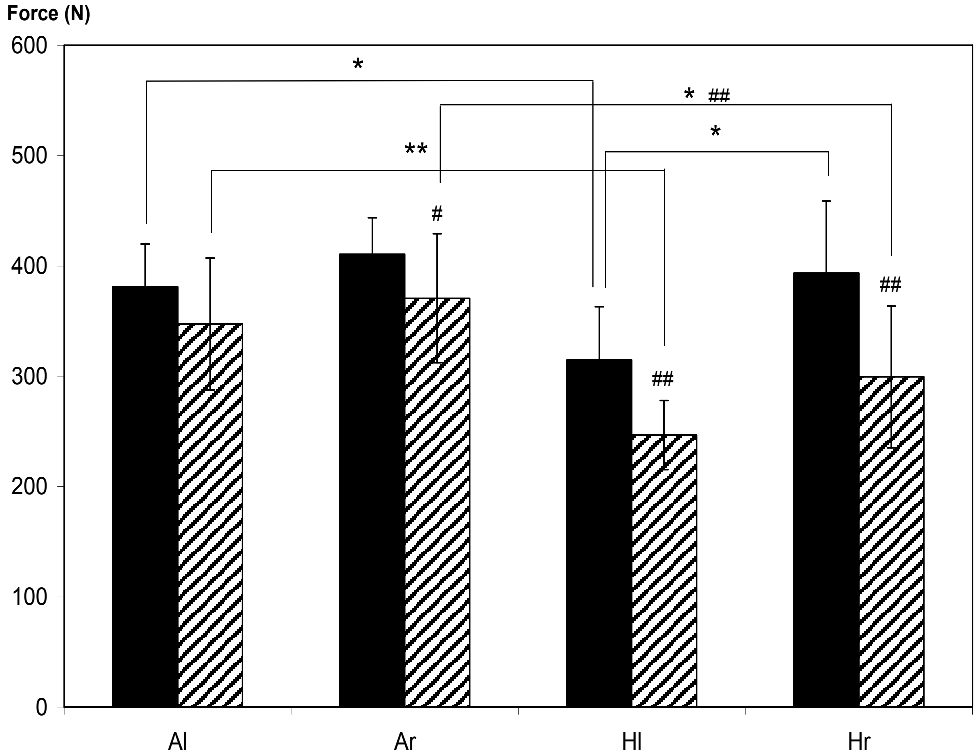
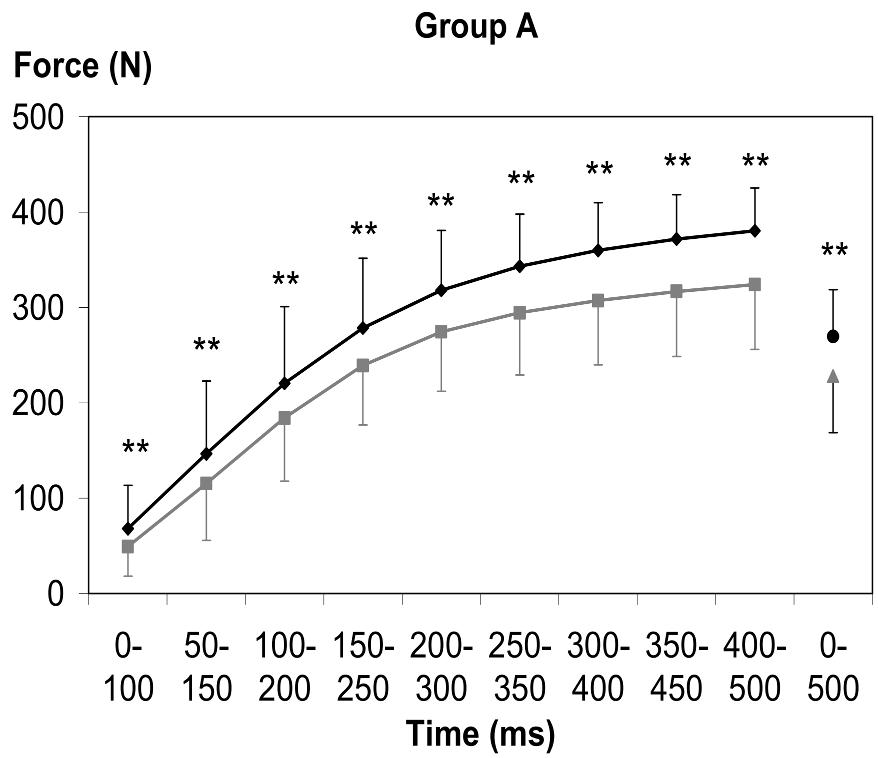


Figure 5. Hand gripping MVCr and MVCl before and after the riding experiment. The black bars represent pre and black and white bars post measurements. # represents the change due to the riding and * the difference between the absolute values. (Al=group A left hand, Hr=group H left hand and the same for the right hand) (* and # $p<0.05$; ** and ## $p<0.01$).



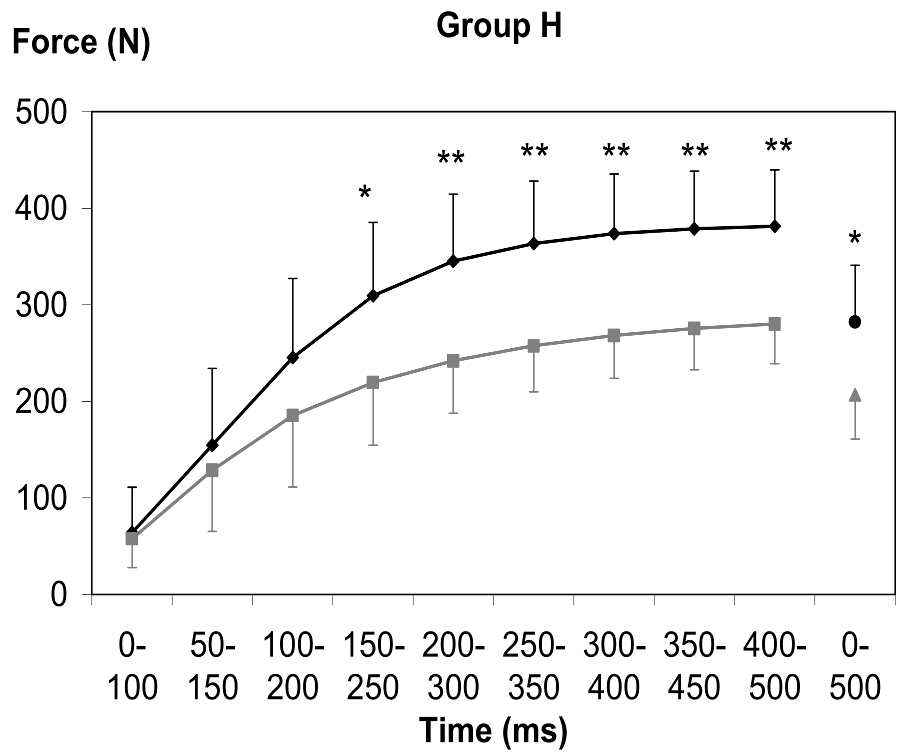


Figure 6. Force-time curve of MVCr during hand gripping before and after riding. Black line represents pre and grey line post measurements. * represents the difference between pre and post measurements. (*p<0.05; **p<0.01).

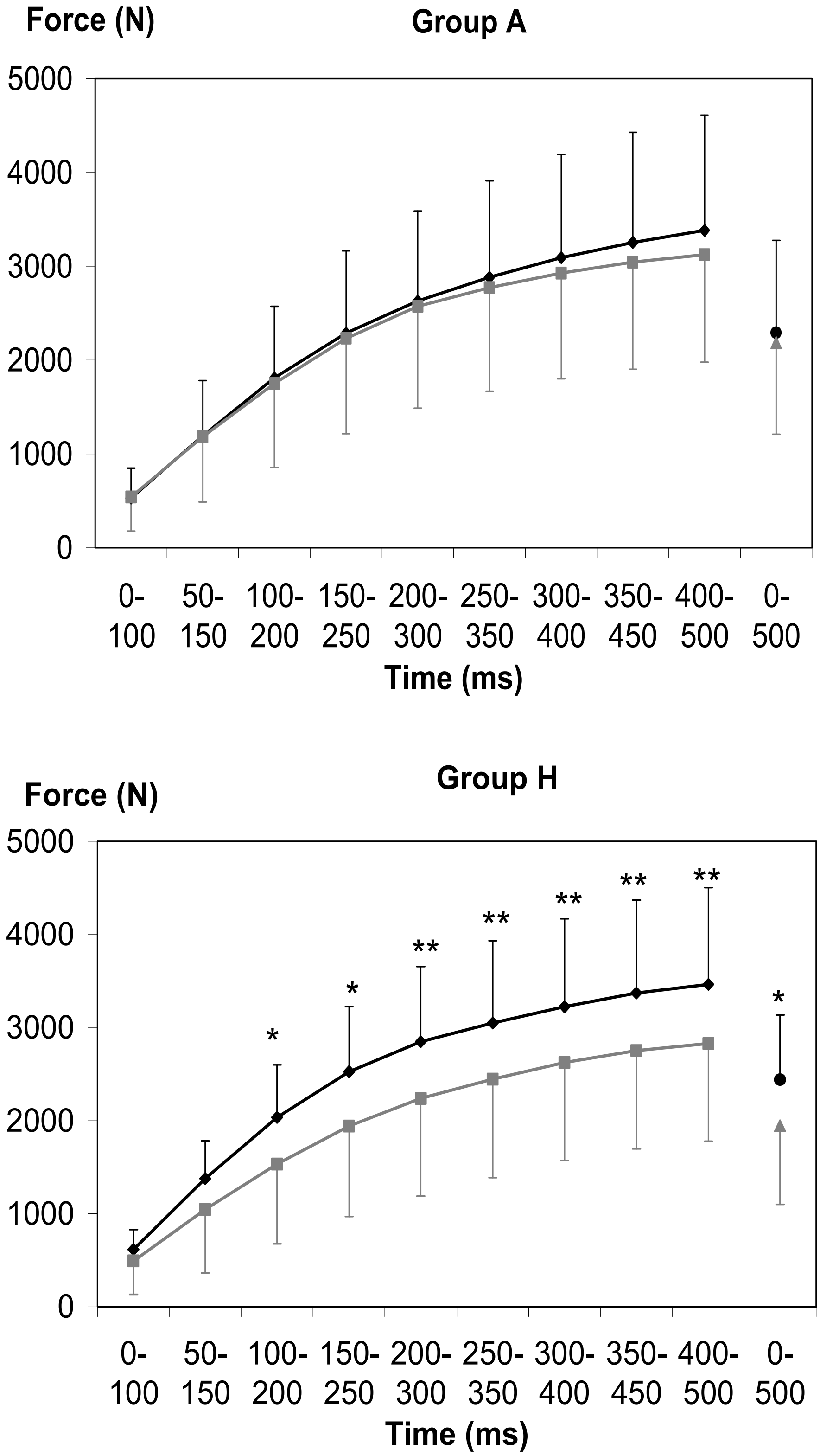


Figure 7. Force-time curve of leg extension MVC before and after riding. Black line represents pre and grey line post measurements. * represents the difference between pre and post measurements. (*p<0.05; **p<0.01).

A significant reduction (16 ± 5 %) in MVC of the arm flexion was detected in group H (from 705 ± 80 N to 623 65 N) but not in group A (706 ± 173 N and 674 ± 126 N). The MVC of the combined group was significantly ($p<0.01$) lower after the riding compared to the value before it . Neither of the study groups showed significant reductions of MVC of arm extension.

The only significant ($p<0.05$) reduction of MVC of leg extension was detected in the combined group. The force-time curve of group H changed significantly ($p<0.05$) after the first 100ms from the beginning of the force development, while no change was observed in group A. (Figure 7). The maximal RFD did not change significantly.

9.3 Physiological responses

The values measured during riding relative to maximum are presented in Table 2. Heart rate remained stable through each third of the experiment. In group A HR varied between 96 and 97 ± 7 % and in group H between 97 and 98 ± 5 % of maximum. Respiration frequency was almost entirely above the maximum during the riding experiment in both groups. It increased from 98 ± 13 % to 106 ± 16 % of maximum in group A and in group H from 109 ± 19 % to 121 ± 15 %. The average VO_2 was clearly below the maximum but in group H some individuals achieved higher VO_2 than in maximal bicycle ergometer test.

Table 2. VO_2, VE, RF, TV, $EE\cdot kg^{-1}$, LA and HR during each third in relation to the maximum in VO_2max test.

	VO_2 %	VE %	RF %	EE/kg %	LA %	HR %
1st third A	86 ± 10	66 ± 5	98 ± 13	77 ± 12	29 ± 8	96 ± 7
2nd third A	75 ± 7	64 ± 5	103 ± 14	69 ± 11	32 ± 11	97 ± 7
3rd third A	69 ± 6	62 ± 7	106 ± 16	64 ± 10	31 ± 6	96 ± 7
1st third H	94 ± 25	74 ± 12	109 ± 19	86 ± 22	41 ± 7	98 ± 2
2nd third H	89 ± 21	72 ± 11	121 ± 21	82 ± 14	36 ± 7	98 ± 3
3rd third H	82 ± 20	67 ± 11	121 ± 15	75 ± 15	32 ± 6	97 ± 5

HR reached the steady state approximately two minutes after the start and remained at the same level until the finish. (Figure 8). The average heart rates during riding were 181 ± 13 bpm and 185 ± 5 bpm for the groups A and H, respectively. Maximal heart rate measured in VO_2max test was exactly the same in both groups. The faster riders could ride at their maximal speed with the lower heart rate in relation to their own maximum than slower riders which could be seen as a significant correlation of the relative HR and riding speed ($r=0.60$, $p<0.05$).

Oxygen consumption reached the steady after two minutes of riding and the maximum during the first sector. It reduced significantly in group A ($p<0.001$) through each sector from 42 ± 3 $ml\cdot kg\cdot min^{-1}$ to 37 ± 3 $ml\cdot kg\cdot min^{-1}$ and 34 ± 3 $ml\cdot kg\cdot min^{-1}$, as a whole approximately by 10 $ml\cdot kg\cdot min^{-1}$. The reduction was not as great in group H, from 39 ± 4 $ml\cdot kg\cdot min^{-1}$ to 37 ± 4 $ml\cdot kg\cdot min^{-1}$ and 34 ± 5 $ml\cdot kg\cdot min^{-1}$, but exceeded the level of significance ($p<0.05$) between the first and the third sector. (Figure 9). The VO_2max of group A and H were 49 ± 6 $ml\cdot kg\cdot min^{-1}$ and 43 ± 7 $ml\cdot kg\cdot min^{-1}$. Significant correlations could be found between relative VO_2 and riding speed during the second ($r=0.70$, $p<0.05$) and the third sector ($r=0.70$, $p<0.05$) but there were no differences between the groups.

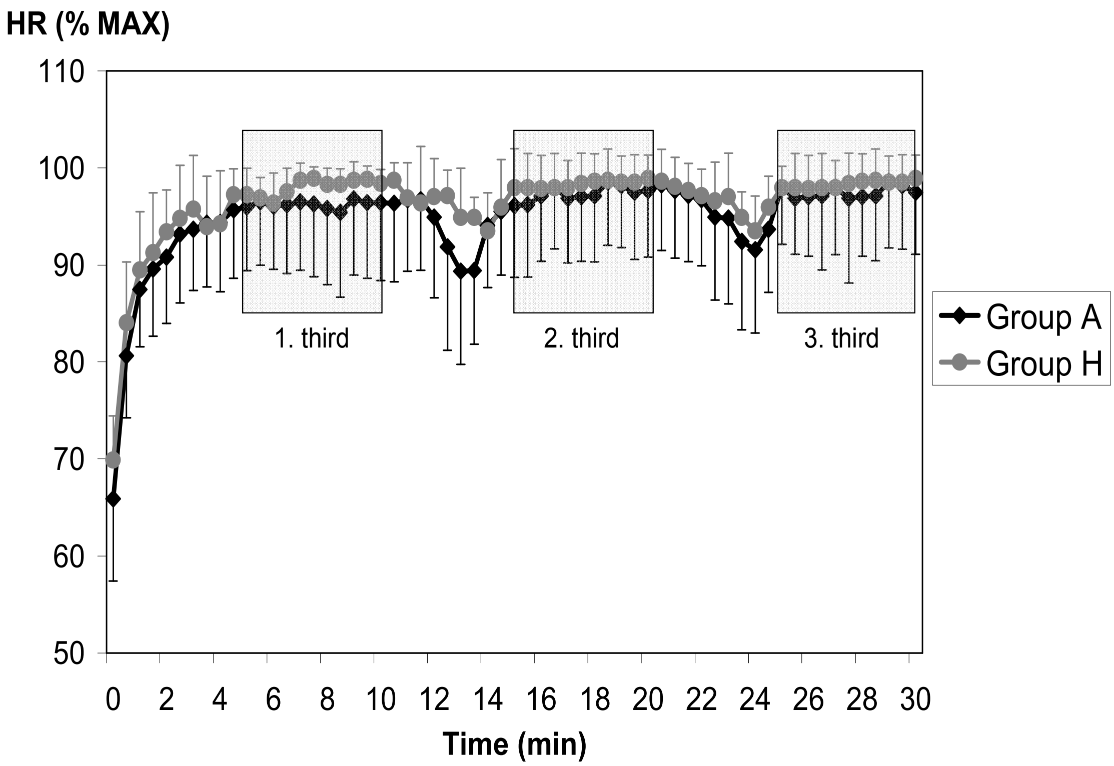


Figure 8. Average heart rate during riding relative to maximum. The shadowed squares represent averaged parts of the first, the second and the third portion.

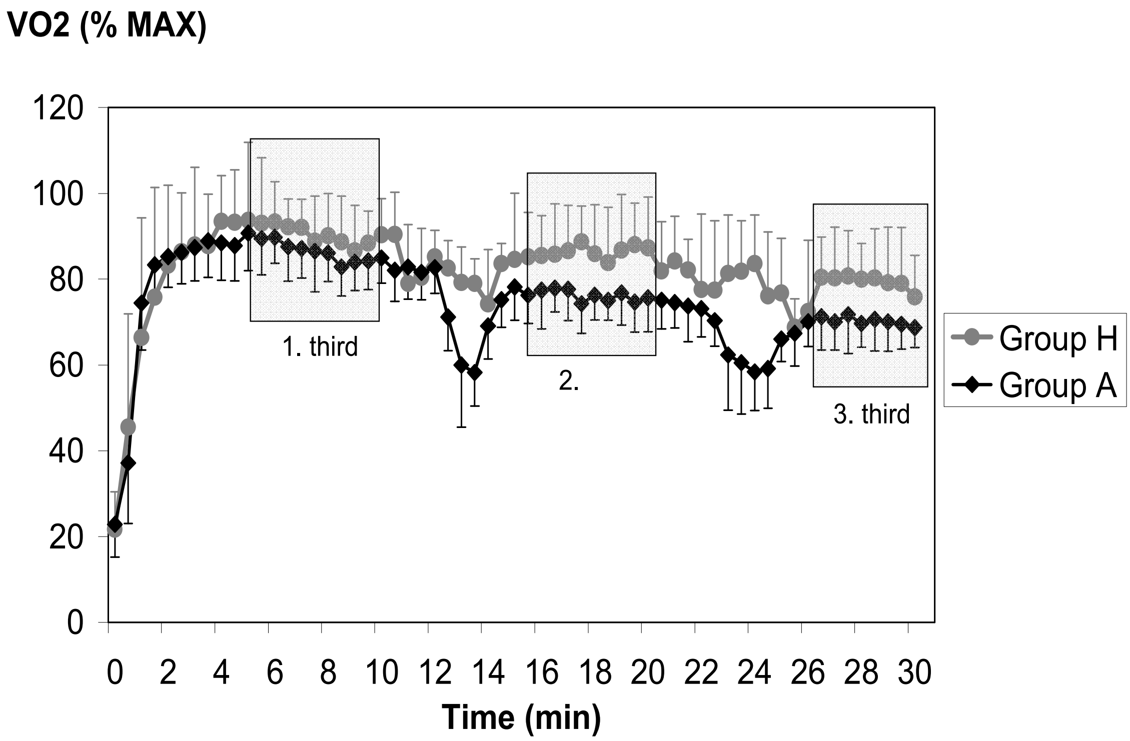


Figure 9. Average oxygen consumption relative to maximum during riding. The shadowed squares represent averaged parts of the first, the second and the third portion.

Respiration frequency increased significantly ($p<0,01$) during the riding experiment after reaching the steady state approximately a minute after the start. In group A it increased from 54 ± 5 bpm to 57 ± 6 bpm and 58 ± 7 bpm. In group H RF was clearly above the maximum reached in VO_2 max test increasing from 56 ± 7 bpm to 61 ± 8 bpm and 60 ± 10 bpm during riding. High RF was interestingly equalized by significantly ($p<0.01$) reducing and relatively low tidal volume. Ventilation also decreased ($p<0.01$) during riding, because TV decreased more in relation to increasing RF. During the first third VE was 109 ± 9 $l·min^{-1}$and 106 ± 15 $l·min^{-1}$ in groups A and H respectively but reduced finally during the third portion to 102 ± 12 $l·min^{-1}$ and 94 ± 15 $l·min^{-1}$.

When all the riders were arranged as individuals according to riding speed, there was a significant relation ($p<0.05$) between the relative $EE·kg^{-1}$ and riding speed during the first third and ($p<0.01$) during the second and third portion. The energy expenditure during riding was approximately 13.5 ± 2.5 $kcal·min^{-1}$ which means that during a 35-40 minutes race the average EE was about 450-550 kcal for approximately 70 kg person. The energy expenditure during riding expressed as METs was approximately 11 ± 1.

Differences in blood lactate levels could be seen during the first third of the riding test when LA of group H differed significantly ($p<0.01$) from group A. While LA of group A remained stable (4.0 ± 1.2; 4.4 ± 1.8; 4.2 ± 1.0 $mmol·l^{-1}$), there were a clear reduction in group H levels after the first third (5.7 ± 1.0; 4.9 ± 3.3; 4.6 ± 0.7 $mmol·l^{-1}$) Finally after the third portion the values of group H differed significantly ($p<0.05$) from the values measured after the first third. (Figure 10). Blood lactate had also significant ($p<0.05$) relation to riding speed after the first third. However, after the second and third the differences were not significant.

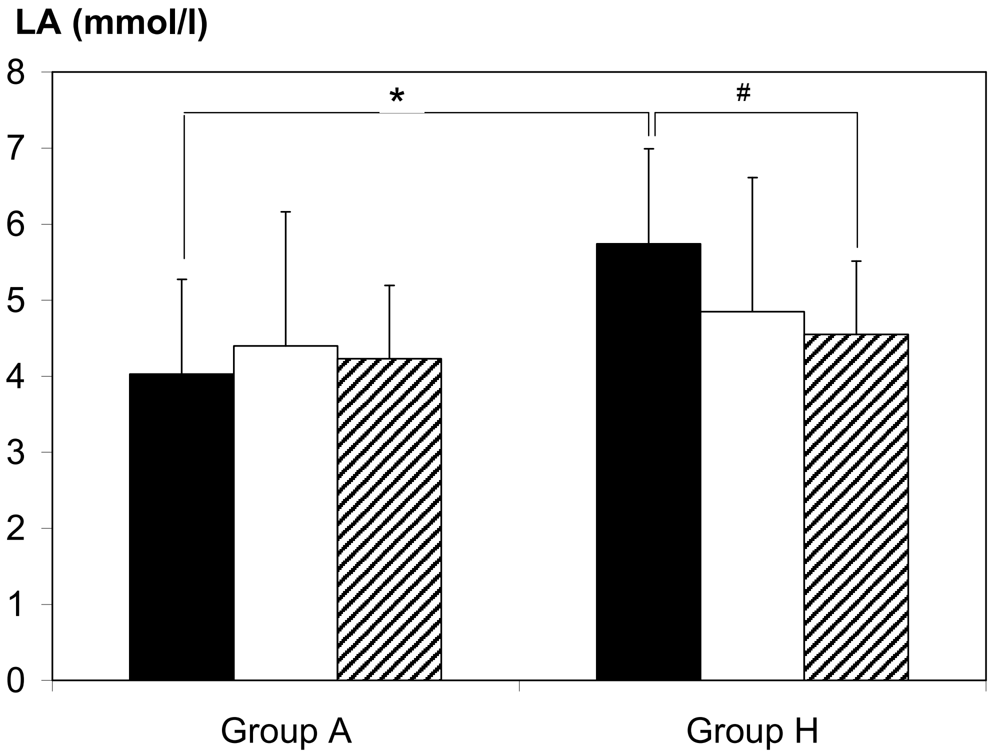


Figure 10. Blood lactate of both groups immediately after each third. The black bars represent the measurement after the first third, white bars after the second and black and white bars after the third portion. # represents the change due to the riding experiment and * the difference between the absolute values.

9.4 Muscle activation during the race

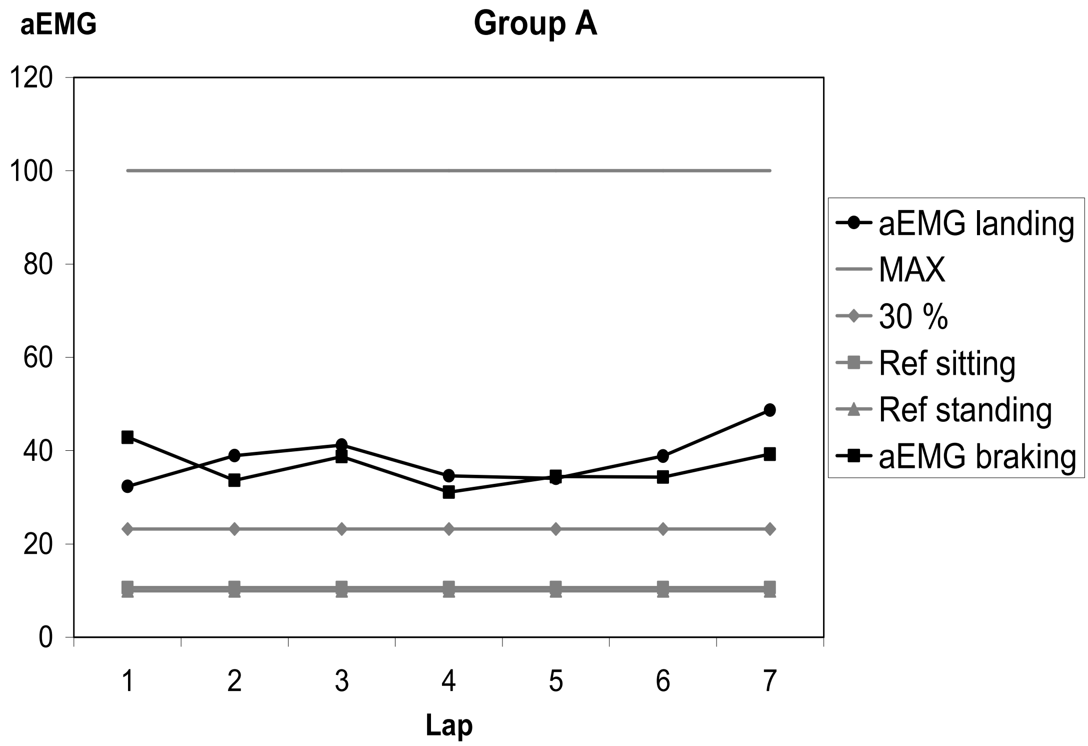
During the riding muscle activation significantly increased above the reference riding and 30 % MVC values. Interestingly, aEMG of FF was even higher during riding than during the maximal hand gripping. Activation of TB during riding was approximately 60 – 80 % of maximum, while the activation of VL,VM and TB varied between 24 – 45 % of the maximum depending on the rider. However, the average EMG amplitude did not change in either of the groups during riding. (Table 3, figure 11).

There were clear differences in muscle activation patterns, if the jump was jumped straight over the table top to the downhill or first on the table top and then forward by another jump. When jumping straight to the downhill, which is the faster way, the muscles are strongly activated once, when the wheels touch the ground. During the flight phase muscles can be quite relaxed. By contrast, if the jump is jumped first on the table top and then again to the downhill, muscles are strongly activated twice and the relaxation during the shorter flight phase is not as clear. It could also be observed that during the braking, the activation changes continuously but there is not so clear relaxation between. Continuous, rapidly changing tension is maintained through the braking phase but group A riders could relax antagonist muscles better than group H riders when agonist was activating. However, during the very high impacts, as landing from a jump, both agonist and antagonist activate simultaneously.

Table 3. Average aEMG relative to the maximal activation during MVC (% of maximum) # represents the difference between landing and braking versus reference riding values. * represents the difference between reference sitting and reference standing. # and *p<0,05; ## and **p<0,01

Group A	VL	VM	BB	TB	FF
Landing	24##	38##	44	66##	91##
Braking	32##	36##	31	62##	116##
Ref sitting	4*	11	19	16*	40
Ref standing	8*	10	20	29*	31

Group H	VL	VM	BB	TB	FF
Landing	41#	42#	25#	74#	143##
Braking	45#	40#	29#	68#	178##
Ref sitting	5*	7	9	13*	69
Ref standing	13*	13	10	32*	37



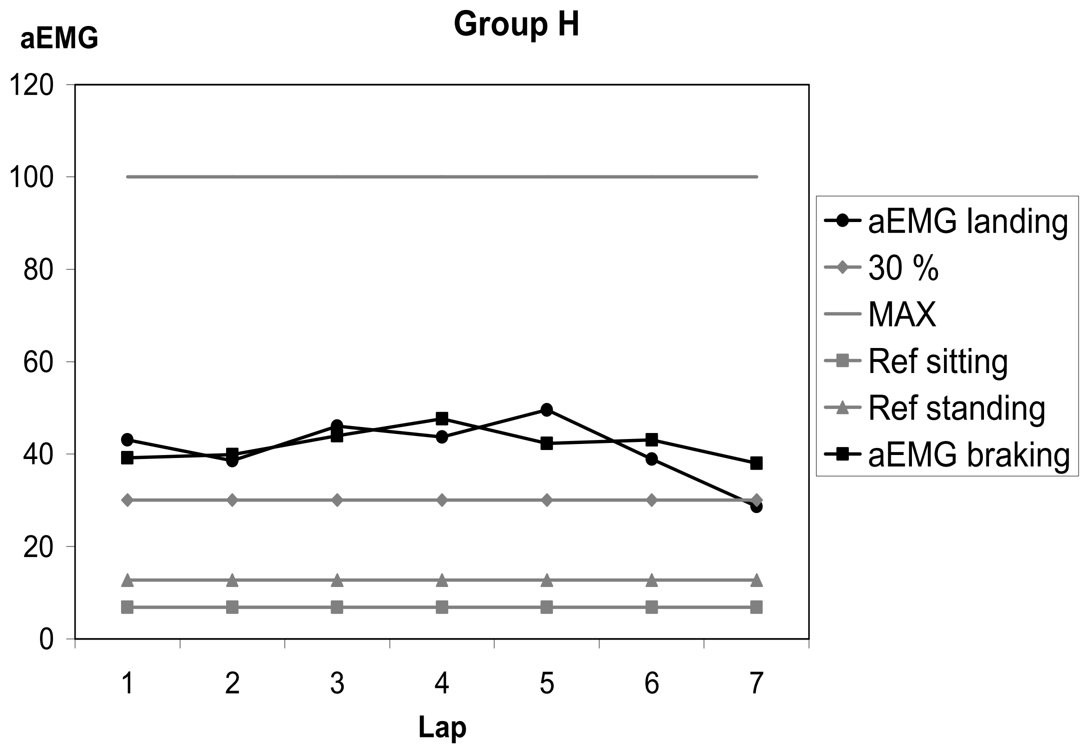


Figure 11. Average aEMG of VM during landing and braking of each lap. Maximal, reference and 30 % MVC activation are presented as straight lines.

10 DISCUSSION

The present study showed clearly that significant alterations in cardio-respiratory and neuromuscular functions could be observed due to motocross-riding. While the average HR and RF were the whole time during riding near the maximum (measured by the maximal bicycle ergometer test) and sometimes even higher, VE, VO_2, and lactate were continuously approximately near the anaerobic threshold levels. However, there were clear reductions in VO_2, VE and in LA in group H, while no changes were observed in group A during the riding experiment. Only HR remained stable throughout each three third of the riding experiment.

Both lower and upper body muscles activated strongly during riding but still not to a similar extent in relation to their maximum. The EMG activity of FF was higher than during maximal hand gripping, while VL and VM activation was somewhat over one third of maximum. In spite of that, aEMG remained similar throughout each lap in each muscle examined.

The riding session led to significant reductions in isometric MVC in hand gripping, arm flexion and leg extension. The force-time curve reduced to lower levels in both groups in hand gripping and in leg extension only in group H.

The present data showed that high heart rate levels were observed compared with lower expiration kinetics levels but no exact explanation can be offered. However, this exceptionally high heart rate for such a long period of time have been reported in most of the studies related to physiological responses during motocross riding (Collins et al. 1993; Odaglia & Magnano 1979; Saltin 1975, 61; von Lehmann et al. 1982) and also in the studies related to motorsports in general (Schwaberger 1987). Psycho-emotional stress (Schwaberger 1987) and also isometric muscle work have been suggested as possible reason for that (Collins et al. 1993; Odaglia & Magnano 1979; von Lehmann et al. 1982). In this study, besides measured expiration kinetics, LA, EMG activity and the reductions in isometric MVC points out that the most of the rise in HR is due to the physical activity. The lactate levels were lower than measured by von Lehmann et al. (1982), approximately 4-6 mmol/l in this study compared with those of 6-8 mmol·l^{-1} reported earlier (von Lehmann et al. 1982). These differences may occur, for example, due to different subjects, track, racing status, motorbikes and measuring equipments. However, there is also room for discussion about the magnitude of psychological factors influencing HR. It must be remembered that also the rise in excretion of psychological stress hormone catecholamine has been pointed out during motocross (von Lehmann et al. 1982) and car-racing (Schwaberger 1987) which has also an effect on HR. The exceptionally high heart rate at the start situation supports the psycho-emotional theory. Both von Lehmann (1982) and our present study could observe the same phenomenon, which included also great SD. This may be due to different level of anxiety before the riding. However, it may also be considered that wearing the riding gear may increase the body temperature and further increase the heart rate. The sweat evaporation may be restricted especially by the helmet, knee braces/guards, boots, kidney belt and chest protector.

Expiration kinetics has been studied less than heart rate and blood lactate. In fact, a few studies concerning expiration kinetics in motorsports have been made in car-racing. In motocross there are only suggestions of VO^2 based on the HR and LA. Based on the LA and HR, it has been suggested that VO^2 during riding is approximately 70-90% of the maximum. The same variation was detected in this study. Some individuals could achieve even higher VO^2 during riding compared with maximal exhaustion by the bicycle ergometer. Obviously, larger muscle mass is working during riding than bicycling.

Interestingly, VO_2 and VE reduced continuously during riding. The reduction in VE was due to the reduction of TV and the rise of RF. The reduction of TV may be due to the rise of RF or vice versa. One explanation could be the exhaustion of pulmonary muscles, when RF must be accelerated to ensure the adequate oxygen supply. In this case, it was not enough and also VO_2 reduced. However, it did not have an effect on lap times. One could suggest that the riders were not riding as economically at the beginning of the riding experiment as they could have. TV was exceptionally low during riding, probably because of large impacts and isometric muscle work. The spine must be supported by holding breath and that may influence to the breathing pattern.

When expiration kinetics and blood lactate were compared with maximal riding speed, a significant relationship was observed. Faster riders could ride more economically at their maximal speed compared with slower riders. This was supported by greater reductions of MVC and force-time curve of group H riders than in group A. Also EMG data show some signs of better agonist-antagonist cooperation and slightly lower aEMG of different muscles of group A riders. The reason that the difference did not reach statistically significance was probably in part due to the small number of subjects. It may also be concluded that faster riding speed does not necessarily demand greater muscle work, if there is more skill to be used or the use of more muscle work does not necessarily improve the riding speed.

Based on the greater relative muscle activity of the upper body muscles, it may be suggested, that also the greatest relative stress is directed to the upper body muscles during landings and brakings. However, it must be recognised, that the activation was different when comparing landing and braking. During the landings the activation burst is more rapid and lasts for a shorter period, while during brakings the activation is more stable and continuous depending on the size, shape and distance of the braking bumps.

In motorsports, there is always a vehicle which may partly influence the results. In motocross, for example, the weight of different motorbikes, the power of the engine and the settings of the carburettor and suspension are important factors during fast riding. The settings are personal and an essential part of racing and economic riding. Therefore, it was important that each rider rode with their own motorbikes to achieve the most natural riding and reliable results.

The classification between group A and group H is clear but the speed difference may vary more in group H than between some riders at the different groups. Therefore, some results were better to present directly relative to riding speed. It must also be pointed out that the number of subjects should have been larger, which would probably have led to the significant differences between the groups.

A motocross-race is a physically and mentally challenging event where muscle activation and the force needed fluctuates along with rapidly changing moments. Muscle actions are both isometric and dynamic varying due to the different parts of the track such as in this study during landings and brakings. Even at the maximal speed of each individual, the most economic riders are the fastest riders, considering the maximal capacity. The riders also became more economic towards the end which further suggests that the riders seem to perform unnecessary work at the beginning. In future, it would be interesting to examine the actual force levels, economy and muscle actions in different situations during riding. This information could be used to develop the sport specific training methods and also the different components of the motorbikes.

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