

ACUTE NEUROMUSCULAR RESPONSES TO CAR RACING

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ABSTRACT

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Purpose: The primary purpose of this study was to determine racing car drivers' acute neuromuscular responses to race driving. The secondary purpose was to compare the cardiovascular loading of driving to that of maximal rowing action.

Methods: The subjects of the present cross-sectional study ($n = 9$) were international level karting drivers. The study was performed in two parts; the laboratory tests and driving test. All subjects took part to the laboratory tests and five of the subjects performed also the driving test. The rowing tests consisted of indoor rowing started at the power of 90 watts and the load was increased 30 watts every third minute until voluntary exhaustion. In the driving test each driver drove with his own kart for 30 minutes in a simulated full speed race including one pit stop in a halfway. The strength test protocol consisted of five maximal voluntary contraction (MVC) isometric strength tests (neck lateral flexion to right, shoulder flexion, grip strength, bilateral leg extension and bilateral plantar flexion). The same strength test protocol was accordingly made four times; before and after the maximal rowing test and before and after the driving.

Results: Average maximal oxygen consumption ($VO_{2\max}$) of the rowing test was $47,6 \pm 5,4$ ml/kg/min and maximal rowing heart rate was 189 ± 5 bpm. In the driving test, average heart rate of 30 minutes of driving was 139 ± 12 bpm. Maximal blood lactate (bLa) in rowing was $12,2 \pm 2,1$ mmol/l and $3,3 \pm 1,7$ mmol/l after 15 minutes of driving and $3,1 \pm 1,6$ at the end of driving. Maximal strength was found to decrease systematically both after rowing and driving. The decrease in maximal strength was systematically more after driving than rowing. Significant differences between the driving and rowing-induced changes were found in shoulder and plantar flexor strength actions. The decrease in the change of the force-time curve was significant ($p < 0.05$ and $p < 0.01$) between pre and post driving in shoulder test.

Conclusion: The present results indicate that considerable loading of the neuromuscular system takes place in competitive driving. This study also indicates that while there is high physiological and moderate neuromuscular loading in maximal rowing, competitive race driving seems to be characterised by moderate physiological and high neuromuscular loading. Driving seems to strain the neuromuscular system due to G-forces and vibration.

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1 INTRODUCTION

Sport science research in the field of motor sport is limited. There has, however, been some discussion about racing drivers' mental and physical stress from the early 1970's (Falkner 1971; Falkner 1972; Taggard & Carruthers 1971b). Until the late 1980 it was a common view that car racing is mainly emotionally challenging, with no physical demands (Schwabberger 1987; Taggard & Carruthers 1971a). According to the research data from 1990 to these days, car racing seems to be physically demanding as well (Backman et al. 2005; Jacobs & Olvey 2000; Jacobs et al. 2002; Lighthall et al. 1994). It is now reported that top drivers have reached the levels of physical effort similar to those reached in many traditional sports such as football or basketball (Dickey & Gavin 2002).

Physiological strain to racing driver consists of many sources. A narrow driving position and the seat belts decrease the power of the muscle pump system and weaken the function of circulation. When braking, cornering and accelerating, drivers have to use lot of static and dynamic muscular effort because of control a car of 3 – 4,5 G forces (Jacobs et al. 2002; Klarica 2001). Three vibrations, below 10Hz, 80 – 90 Hz, above 150 Hz, affect to drivers' neuromuscular system through the hard suspension of a fast race car (Tieteen Kuvalehti 1994). Heat and high humidity decrease also physical performance of the drivers (Jareno et al. 1987; Klarica 2001; Walker et al. 1998). Psycho-emotional stress of driving loads the body of the drivers (Schwabberger 1987; Taggard & Carruthers 1971a). All of these factors together produce the physiological and neuromuscular responses to car racing and make it physically challenging.

2 PHYSIOLOGICAL RESPONSES TO CAR RACING

2.1 Heart Rate

In all previous research experiments, driving heart rate has been reported to be very high. In general, driving heart rates have been found to be 82 – 93% of individual maximal heart rate (Jacobs & Olvey 2000; Jacobs et al. 2002; Lighthall et al. 1994; Schwaberg 1987).

Schwaberg (1987) reported heart rate during car racing reached a mean level of 174 beats per minute (bpm) corresponding to 90% of the maximal heart rate achieved at the end of exhaustive bicycle ergometry. Jacobs et al. (2002) have measured a mean HR value of 152 bpm when driving at competitive speed on the road course.

The only competition situation research concerning car racing is published by Lighthall et al. 1994. They summarized heart rate to be in average 169 bpm on the road course racing. Typical HR curve in a race of one hour is shown in figure 1.

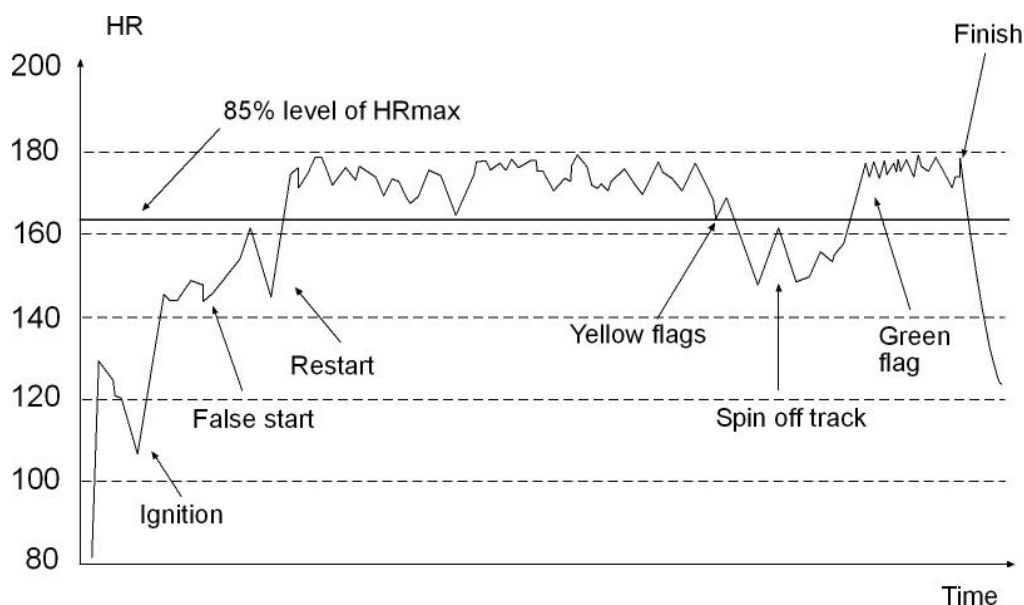


Figure 1. HR recorded during road course race (Lighthall et al. 1994)

2.2 Oxygen consumption

Oxygen uptake during race driving has been measured to correspond 79 - 83% of the drivers' maximal oxygen consumption (Jacobs & Olvey 2000; Jacobs et al. 2002). Jacobs & Olvey (2000) reported oxygen uptake to be increased to over 3 l/min at race velocity. This metabolic demand was more than 75% of peak VO_2 exhibited during bicycle ergometry and greater than 100% of the arm ergometry VO_2 peak. Peak average value of oxygen uptake

(VO₂) reached during a driving period was 3,35l/min (38,1ml/kg/min). Jacobs et al. (2002) reported average oxygen consumption level of 38,5ml/kg/min at full speed road course driving.

2.3 Lactate and catecholamine excretion

Schwaberg (1987) has reported blood lactate level of 1,6mmol/l before and 3,3mmol/l after car racing. Post maximal bicycle ergometry test value of 13,2mmol/l was reported. He concluded that the maximal lactate concentration after exhausting progressive bicycle ergometry is to be expected in moderately trained subjects. Also during physical stress with emotional-affective participation, lactate concentration increases slightly because of rise of muscular tone and direct activation of glycolysis via catecholamines. Therefore, the increased lactate concentration after car racing can be traced back, on one hand to the high emotional stress, and on the other hand to a certain dynamic and static muscular component. (Schwaberg 1987.)

It is also pointed out that in the case of sports with large components of psychological stress, such as car racing, it is assumed that the elevated lactate level was due to a large extent by the increased secretion of catecholamines, with its resulting stimulation of glycogenolysis and glycolysis (Kindermann & Keul 1977). Schwaberg (1987) perceived the catecholamine excretion during the race (252,3ng/min) reaches more than twice the value obtained after exhausting exercise (121,9ng/min) and almost eight times the value of during night rest (32,8ng/min) (Figure 2).

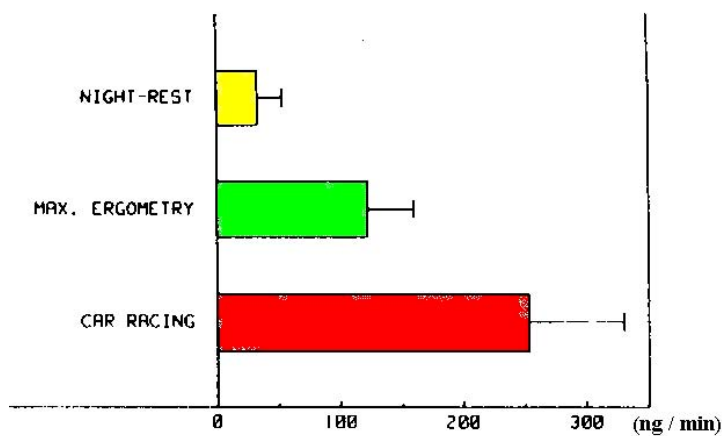


Figure 2. Free catecholamine excretion in urine (adrenaline + noradrenaline) in different situations (Schwaerger 1987).

3 NEUROMUSCULAR RESPONSES TO CAR RACING

3.1 Influence of G-forces on electromyographic activity

When a human being is under the influence of G-forces, for instance in race car, he has to active his muscles to stabilise the position. This phenomenon is partly autonomic and partly voluntary. Table 1 presents typical muscle activation levels of the influence of G-forces in a sitting position.

Table 1. Muscle activity levels in different G-force stress situations.

Reference	N	G-level	Muscle	Activity (%/MVC)
Kobayashi et al. 2002	21	+ 7Gz	Rectus abdominis	10-40%
Hewson et al. 2001	6	2 G	Wrist flexors	20.8-26.1%
Hewson et al. 2001	6	2 G	Biceps brachii	13.0-29.8%
Hewson et al. 2001	6	2 G	Triceps brachii	26.4-28.4%
Hewson et al. 2001	6	2 G	Deltoideus	14.1-23.5%
Hewson et al. 2001	6	2 G	Vastus lateralis	28.8-61.4%
Chen at al. 2004	20	+ 1Gz	Breathing muscles	29-55%

Neck muscles are loaded relatively very high during G-force stress. According to Hämäläinen & Vaharanta (1992) the muscular strain increases with increasing G-forces and head movements. Under +7,0 Gz the mean muscular strain was 5,9-fold compared with +1,0 Gz and was 39,9% of the MCV. In some individuals, the muscular tolerance (100% of the MVC) was ipsilaterally reached already under +4,0 Gz with concomitant movements and twisted positions of the head. The influence on the MVC of head movements on +4 Gz-level is shown in figure 3.

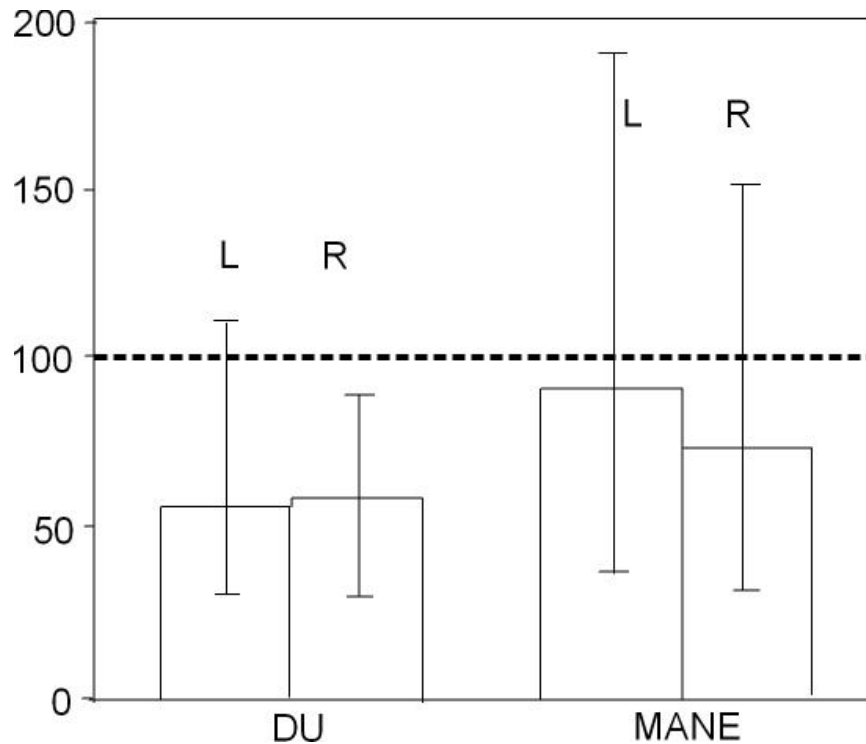


Figure 3. Strain on the cervical erector spinae muscles caused by +Gz-forces in percent of the MVC under sustained +4,0 Gz during head movements (DU = flexion – extension, MANE = rotations). The columns represent the mean of the strain on the left (L) and right (R) cervical erector spinae muscles. The vertical bars show the inter-individual differences. The interrupted horizontal line shows the level of 100% of the MVC (Hämäläinen & Vaharanta 1992).

3.2 Influence of vibrations on electromyographic activity

Vibration influences muscle spindles (between 0 – 200 Hz) and Golgi tendon organs. Vibration achieves the tonic vibration reflex in the nerve-muscle system. This means that muscle spindles can react to vibration as stimulus by stimulus from 0 Hz to 150 – 200 Hz. In these frequencies alpha motoneurons become activated by afferent muscle nerves automatically when EMG-activity and the MVC are increased. Usually the MVC increases by increasing vibration. Often the phenomenon inhibits antagonist activation. (Berthoz 1988.)

Rohmert et al. (1989) have examined the influence of 30 Hz vibration on EMG in arm extension movements. All the arm muscles showed an increased EMG index during

exposure vibration compared to exposure without vibration. The majority of muscles reacted very strongly and the EMG index increased as follows: trapezius muscles 40%, flexor muscles 37%, infraspinatus muscles 18% and extensor muscles 14%. The average pushing force was 11% of the MVC during exposure to vibration and 12% of the MVC without it. Gurram et al. (1995) have reported the linear increase of EMG by increasing vibration (20 – 1000 Hz) in arm flexor muscles.

The same kind of observations have found within lower limbs. Cardinale & Lim (2003) compared the influence of vibration frequencies 30 Hz, 40 Hz and 50 Hz on EMG of vastus lateralis. In every mentioned frequencies EMG increased compared to muscle work without vibration. The largest increase of EMG was found in frequency of 30 Hz. According to Sabine et al. (2003) the vibration of 75 Hz increased significantly EMG of rectus femoris and biceps femoris during walking.

However, all the available data is not consistent. Some studies have shown no influence of vibration on EMG at all (Zimmermann et al 1993; Gomes de Olivera et al. 2001; Rosenkranz & Rothwell 2003). Torvinen et al. (2002) observed a decrease of EMG by vibration. Very short load of vibration does not bring off the tonic vibration reflex (Rosenkranz & Rothwell 2003). A decrease of EMG may be caused by exhaustion of the nerve-muscle system.

4 NEUROMUCULAR PERFORMANCE CHARACTERISTICS OF DRIVERS

In our previous study (Backman et al 2005) we have investigated neuromuscular performance characteristics in open-wheel- and rally-drivers using the cross-sectional study design. The rally drivers had higher ($p<0.05$) grip, shoulder flexion and ankle plantar flexion strength as compared to the control group. The open-wheel drivers showed higher strengths ($p<0.05$) than the controls in neck forces, grip, shoulder flexion and leg extension. The rally drivers were stronger ($p<0.05$) than the open-wheel drivers in grip, plantar flexion and trunk extension forces, while the open-wheel drivers were stronger ($p<0.01$) than the rally drivers in neck lateral flexions and extension forces. (Backman et al 2005.)

Neck strengths seem to play an important role in open-wheel racing because of high lateral G-forces in race driving (figure 3).

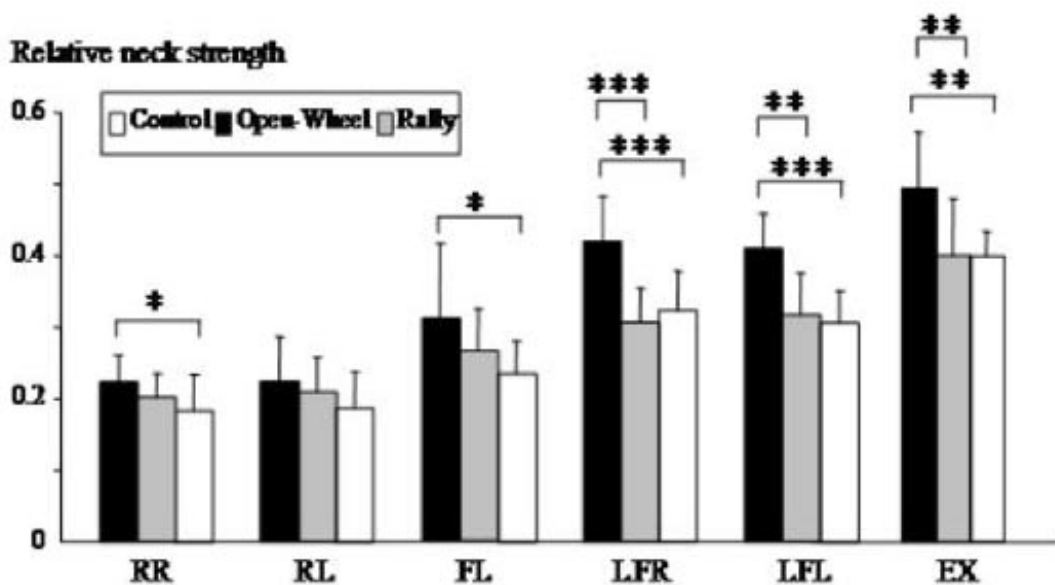


Figure 4. Mean (\pm SD) neck strength (per body weight) in the subject groups (RR=rotation right, RL=rotation left, FL=flexion, LFR=lateral flexion right, LFL=lateral flexion left, EX=extension). *** $p<0.001$, ** $p<0.01$, * $p<0.05$

(Backman et al 2005).

The results of our previous study suggested that the neuromuscular performance specially differs between non-drivers, rally drivers and open-wheel drivers. Thus, there might be some influence of driving on the drivers' neuromuscular system.

5 PURPOSE OF THE STUDY

The primary purpose of this study was to determine racing car drivers' acute neuromuscular responses to race driving. The secondary purpose was to compare the cardiovascular loading of driving to that of maximal rowing. The drivers were loaded separately by both driving and rowing. Rowing is assumed to be a same kind of exercise as driving, because the same muscle groups are activated and the body position is about the same (Rodriguez et al. 1990; Klarica 2001).

6 METHODS

6.1 Subjects

The subjects of the present cross-sectional study ($n = 9$) were international level Finnish male Karting drivers (categories Intercontinental A and Formula A). All subjects who volunteered to the study took part to the laboratory tests and five of the subjects performed also the driving test. The subject's background information and anthropometric data is presented in Table 2. Body fat was estimated by measuring skinfold thickness at 7 different sides according to the method of Jackson and Pollock.

Table 2. Physical characteristics of the subjects ($n=9$).

Variables	Mean (SD)
Age (years)	18 (4)
Years of driving (years)	11 (4)
Height (cm)	173 (5)
Body mass (kg)	63,3 (8,5)
Body fat (%)	8,0 (2,8)

6.2 Overall design of the study

The study was performed in two parts; the laboratory tests and driving test. In the laboratory tests anthropometric measurements, the rowing test and pre and post rowing strength tests were performed. The driving test took place two months after the laboratory tests including the measurements during driving, and strength tests before and after the driving. The same strength test protocol was accordingly made four times; before and after the rowing and before and after the driving. In all the tests, driving shoes were used.

6.3 Strength tests

The strength test protocol consisted of five maximal voluntary contraction (MVC) isometric strength tests. The tests in order were neck lateral flexion to right, shoulder flexion, grip strength, bilateral leg extension and bilateral plantar flexion. The subjects were instructed to exert their maximal force as fast as possible and the total duration of the contractions were 2.5 - 4.0 s (Häkkinen et al. 1998). Two maximal trials were performed on each test and the better trial was taken into the final statistical analysis. If these two trials differed more than 5 % from each other, a third trial was performed. No rest was allowed between the tests and only a brief pause to concentrate was allowed between the trials of each test. All the tests

were performed on special force dynamometer (Figure 5). Maximal isometric strength and force-time curve of MVC were analyzed. The two-way t-test was used for the statistical analyses.

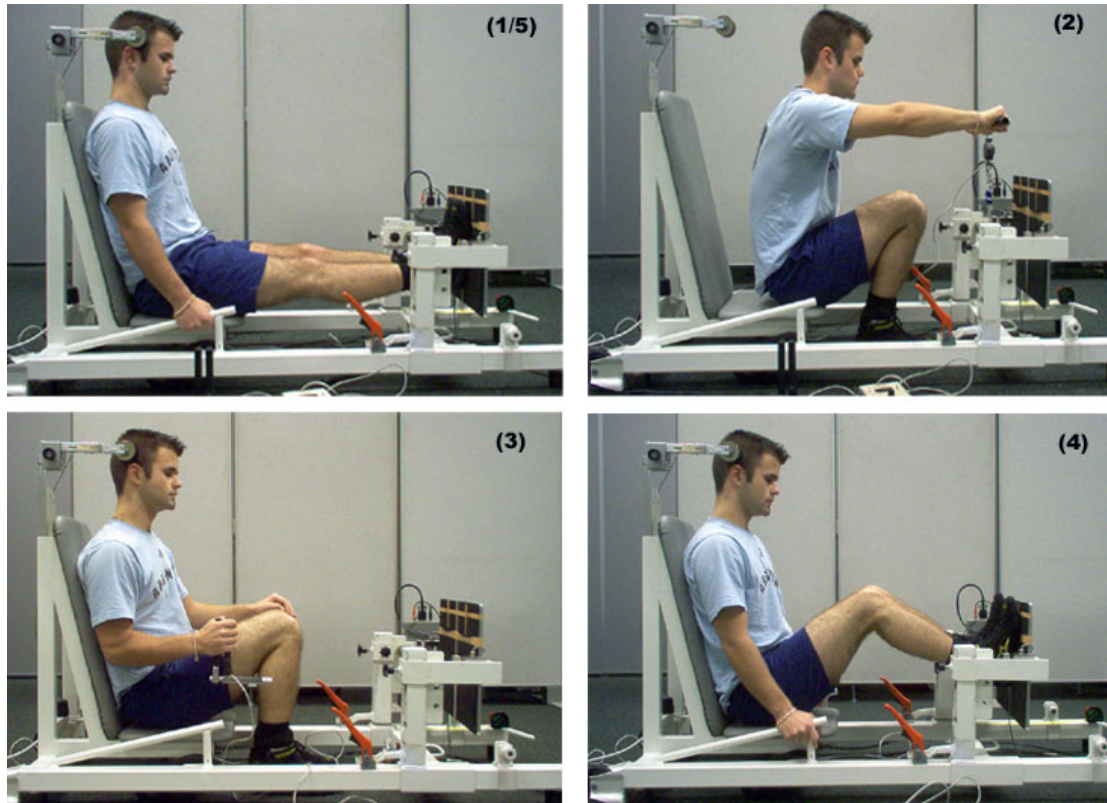


Figure 5. A special dynamometer to measure isometric neck lateral flexion (1), shoulder flexion (2), grip strength (3), leg extension (4) and plantar flexion (5) forces.

In *maximal isometric neck lateral flexion test* the test position (Figure 5; part 1) was standardized by adjusting the trunk of the subjects with a belt so that they were in an upright sitting position. The feet were fully extended and the hands were placed freely over the thighs. Neck lateral flexion force to the right was recorded with the load-cell placed against the middle of the temple just above to the right ear (Ylinen et al. 1999).

Maximal isometric shoulder strength tests were performed using the bar with a force sensor (Backman et al. 2005). In the shoulder flexion test the subject produced force isometrically by sitting in a back straight position and the elbows were fully extended with the 90° shoulder flexion (Figure 5; part 2).

Isometric grip strength (Figure 5; part 3) was tested in a sitting position, and the elbow was flexed at the 90° position (Su et al. 1994). The best trial of the right hand was chosen for the data analysis.

Maximal bilateral isometric leg extension force (hip, knee and ankle extensors) was measured (Figure 5; part 4), while subject was sitting with the knees and hips flexed at 107° and 110° (180° refers to full extension), respectively (Häkkinen et al. 1998).

Maximal isometric plantar flexion force test was performed with the same leg force platform as the isometric leg extension test (Figure 5; part 5). The knees were fully extended and the ankle was set at the 90° position (Kyröläinen & Komi 1994).

6.4 Rowing test

Concept II rowing ergometer was used for the rowing test. Each subject started rowing at the power of 90 watts and load was increased by 30 watts every third minute until voluntary exhaustion (Larsson & Jensen 1999). Heart rate (Polar Electro Sport Tester, Finland) and oxygen consumption (Cosmed K4 breath by breath, Italy) were measured continually during the test. Oxygen uptake and heart rate of each load were calculated as an average of the last 30 seconds. Maximal oxygen consumption (VO_{2max}) was analyzed. Capillary blood sample was taken from a finger tip every third minute to analyse blood lactate level (Lactate Pro blood lactate test meter, Arkray Inc, Japan). The strength tests were performed immediately before and after the rowing test. The time after exhaustion in rowing before the first strength test was less than a minute.

6.5 Driving test

The driving test was carried out on karting circuit of Muro Leccese in Italy. The circuit was 1 250 meters in length and 9-10 meters in width international karting circuit. Each subject drove with his own kart for 30 minutes in a simulated full speed race including one pit stop in a halfway. Capillary blood sample was taken from a finger tip at start, after 15 minutes (pit stop) and after 30 minutes of the race to analyse blood lactate level (Lactate Pro blood lactate test meter, Arkray Inc, Japan). Heart rate was continuously measured in five seconds intervals (Polar Electro Sport Tester, Finland). Strength tests were performed immediately

before and after the driving test. The time from the termination of the race to the first strength test was less than a minute.

7 RESULTS

7.1 Comparison of physiological responses to rowing and driving

Average maximal oxygen consumption ($VO_{2\max}$) of the rowing test was $47,6 \pm 5,4$ ml/kg/min and maximal rowing heart rate was 189 ± 5 bpm. In the driving test, average heart rate of 30 minutes of driving was 139 ± 12 bpm (Figure 6).

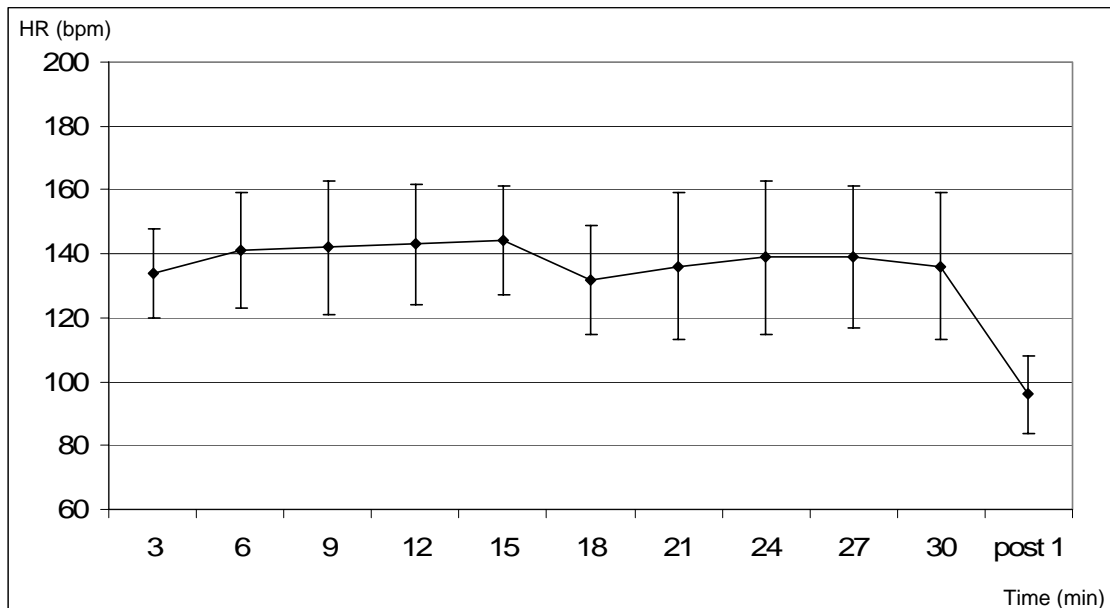


Figure 6. Average heart rate during the driving test.

Maximal blood lactate (bLa) in rowing was $12,2 \pm 2,1$ mmol/l and $3,3 \pm 1,7$ mmol/l after 15 minutes of driving and $3,1 \pm 1,6$ at the end of driving. Oxygen consumption, heart rate and blood lactate with the increasing power load in rowing, and in driving test is presented in Table 3.

Table 3. Mean (\pm SD) values of physiological responses to rowing and driving. (* = Average of 15 and 30 minutes of driving.)

Power (W)	90	120	150	180	210	240	270	Driving
VO₂ (ml/kg/min)	28,8 (3,8)	34,2 (4,5)	38,7 (4,7)	42,9 (6,2)	45,3 (5,3)	47,6 (3,6)	47,3 (3,9)	nm.
HR (bpm)	123 (11)	139 (12)	158 (9)	171 (8)	179 (7)	186 (4)	191 (4)	139 (12)
bLa (mmol/l)	2,3 (0,7)	2,7 (1,2)	3,9 (1,5)	5,8 (2,5)	8,3 (3,5)	10 (1,6)	12,2 (2,1)	* 3,2 (1,7)

7.2 Comparison of neuromuscular responses to rowing and driving

The values of isometric strength tests are presented in Table 4. The subjects of the driving test were weaker than an average subject of the whole group, but no significant differences between the rowers and drivers or pre and post tests were found.

Table 4. Mean (\pm SD) values of isometric strength (N) before and after rowing and driving.

	Pre Row (n=9)	Post Row (n=9)	Pre Drive (n=5)	Post Drive (n=5)
Neck lateral flexion	237 (56)	217 (51)	193 (63)	158 (32)
Shoulder flexion	211 (59)	193 (56)	169 (45)	126 (50)
Grip	499 (106)	435 (67)	383 (137)	366 (117)
Leg extension	2927 (790)	2772 (757)	2696 (1033)	2337 (693)
Plantar flexion	1845 (536)	2022 (556)	1675 (561)	1597 (863)

Maximal strength was found to decrease systematically after rowing and driving (Table 4), except in plantar flexion after rowing. The decrease in maximal strength was systematically more after driving than rowing. Significant differences between driving and rowing were found in shoulder and plantar flexor movements (Figure 7).

The decrease in the change of the force-time curve was significant ($p < 0.05$ and $p < 0.01$) between pre and post driving in shoulder test (Figure 8). In other test actions, no significant differences in the force-time curves were found (Figures 9 – 12).

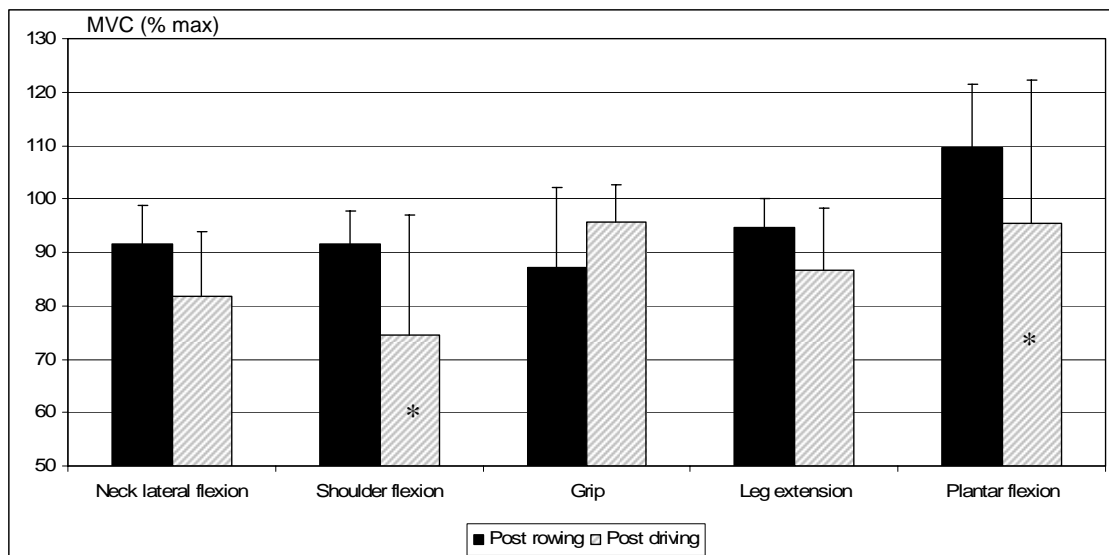


Figure 7. Changes in maximal strength after rowing and driving; * $p < 0.05$. 100 % is pre-rowing/pre-driving strength level.

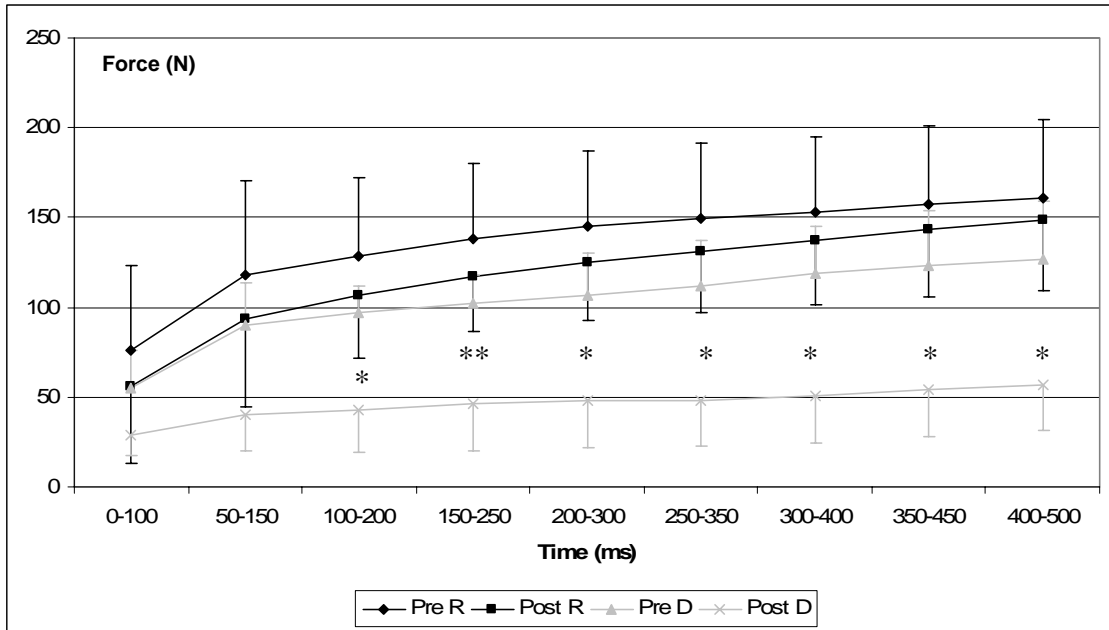


Figure 8. Force-time curve of MVC during shoulder flexion before and after rowing (R) and driving (D), * $p < 0.05$, ** $p < 0.01$.

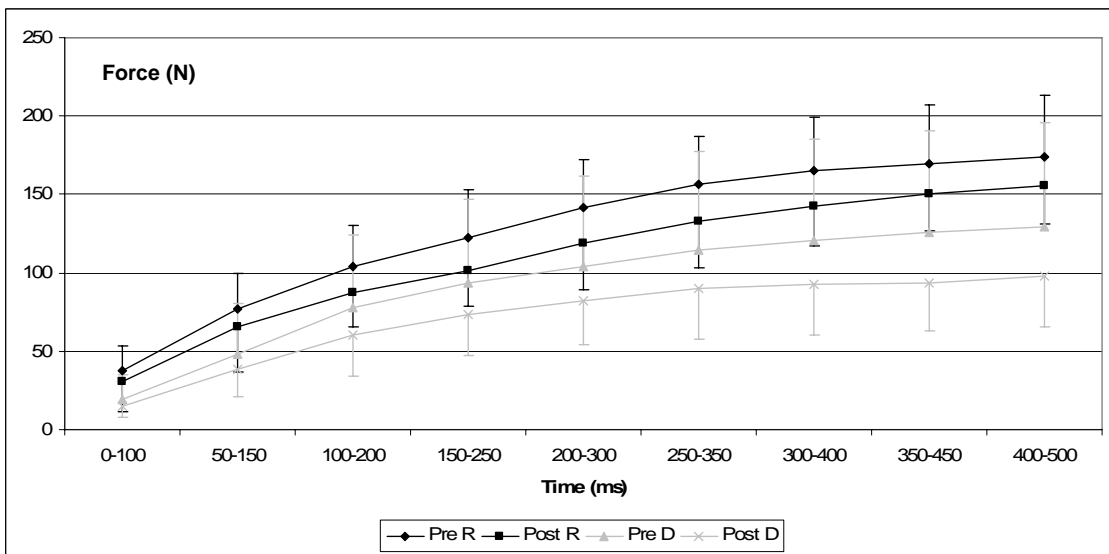


Figure 9. Force-time curve of MVC during neck lateral flexion before and after rowing (R) and driving (D).

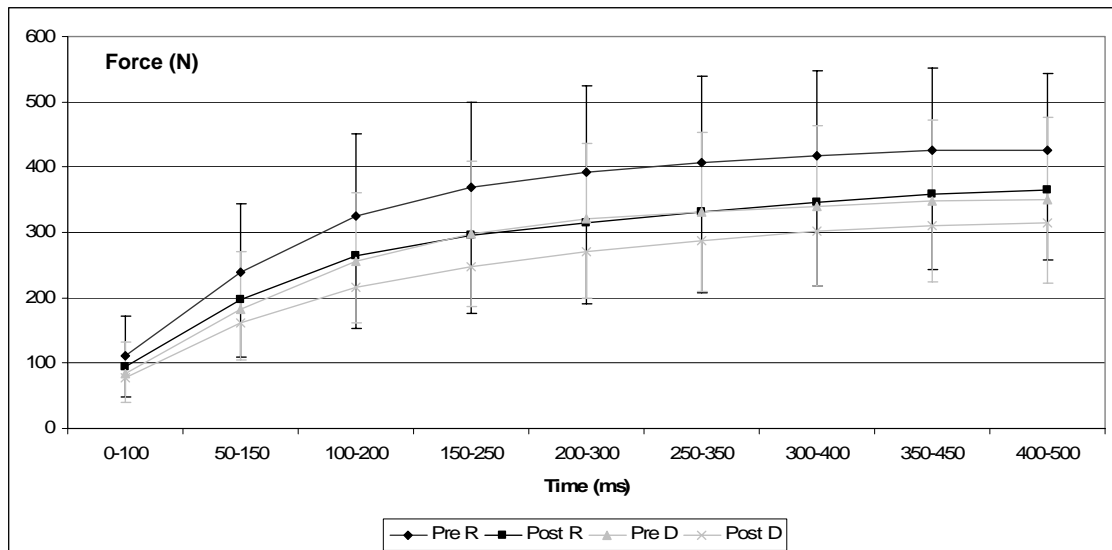


Figure 10. Force-time curve of MVC during hand grip before and after rowing (R) and driving (D).

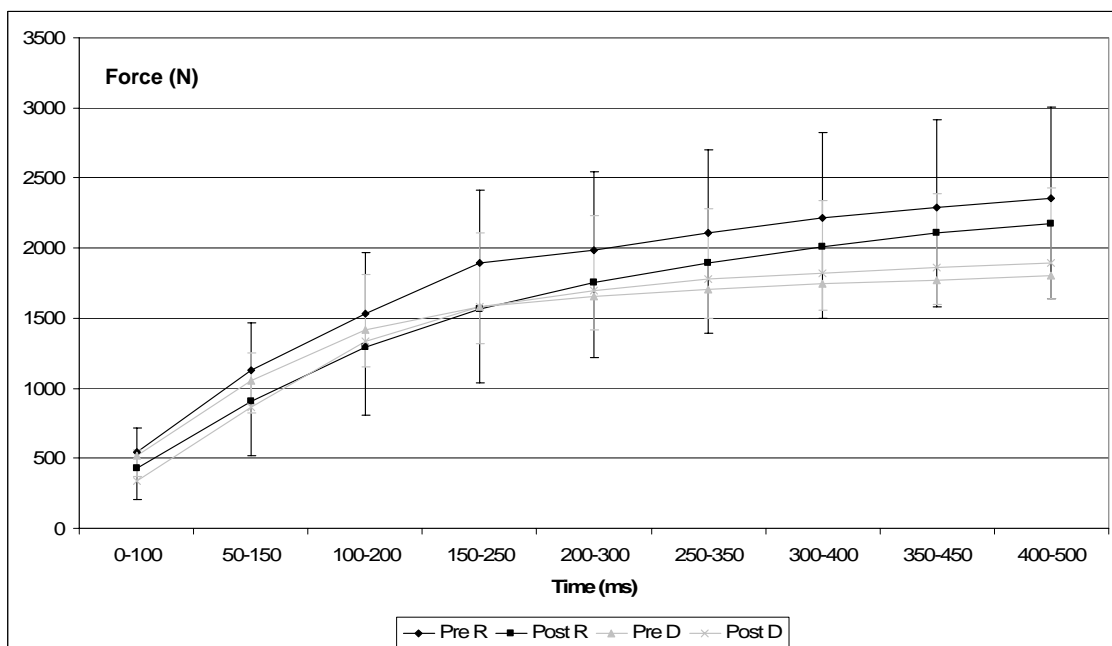


Figure 11. Force-time curve of MVC during leg extension before and after rowing (R) and driving (D).

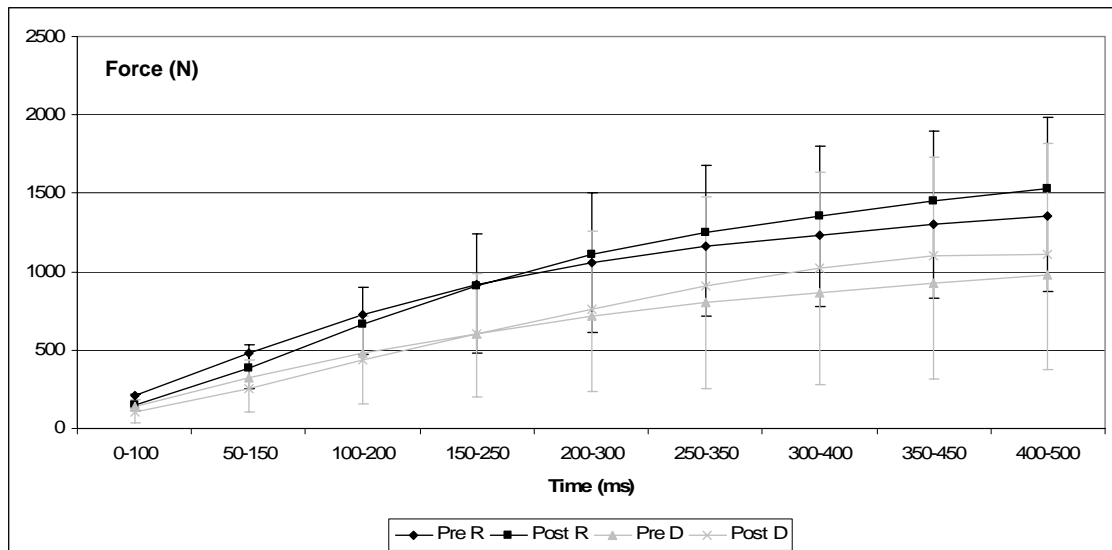


Figure 12. Force-time curve of MVC during plantar flexion before and after rowing (R) and driving (D).

8 DISCUSSION

The primary results of the present study showed that car racing strains both neuromuscular and cardio-respiratory system of the competitive drivers. Neuromuscular performance weakened systematically after driving observed especially as decreases in maximal strength and rate of force production in driving specific muscle groups.

Physiological responses to race driving were found to be quite similar compared to previous experimental findings. Driving heart rate in this study was 74 % of the measured individual maximum. This value is slightly lower than what Jacobs & Olvey (2000), Jacobs et al. (2002), Lighthall et al. (1994) and Schwaberg 1987 have reported. A competition situation (Lighthall et al. 1994), driver's ability to cope with stress and his physical condition (Schwaberg 1987), a type of race car and circuit (Jacobs et al. 2002) are possible reasons which effects on heart rate. We measured a capillary blood lactate level to be relative low, but increased from the resting level. Kindermann & Keul (1977) and Schwaberg (1987) have observed the same phenomenon.

When driving was compared to rowing, similar physiological responses (heart rate, blood lactate) were found in rowing power between 120 – 150 watts. Mean oxygen uptake with that power was measured 36,6 ml/kg/min, which corresponds to 77 % of the individual maximum. Jacobs et al. (2002) measured oxygen uptake to be 79 % of its maximal value during road course race driving.

In our previous study we observed that racing drivers are stronger than non-driver control subjects in neck, hand grip, shoulder flexion and leg extension forces (Backman et al 2005). The results of this study showed that driving loads all these muscle groups, particularly shoulder region. Steering movements and vibration via steering wheel are possible reasons which caused significant decreases in maximal strength and in rapid force production after driving. Although the rowing test was maximal endurance performance until voluntary exhaustion, the response of driving to neuromuscular performance was systematically more significant. This strongly indicates that race driving loads remarkably the drivers' neuromuscular system.

Vibrations during driving may be one reason to cause loading of the neuromuscular system of the drivers. Cardinale & Lim (2003) observed that in all whole-body vibration conditions at different frequencies, average EMG activity of m. vastus lateralis was higher than in the no-vibration conditions. Similarly, Bosco et al (1999) concluded that mechanical vibrations enhanced muscle power and decreased the related EMGi - Power relationship in elite boxers.

From the practical point of view, rowing seems to be a good training method to drivers. According to the present results rowing loads also neck and arm muscles, which have previously been found to be important for elite drivers (Backman et al 2005). Relevant rowing intensities for endurance training seem to be 120 – 150 watts.

Race driving is previously indicated to be physiologically (Jacobs & Olvey 2000; Jacobs et al. 2002; Lighthall et al. 1994) and psychologically (Scwaberger 1987) demanding. The present results further indicate that significant loading of the neuromuscular system takes place in competitive driving. In conclusion, this study indicates that while there is high physiological and moderate neuromuscular loading in maximal rowing, competitive race driving seems to be characterised by moderate physiological and high neuromuscular loading. In other words, rowing strains cardio-respiratory system and driving strains also the neuromuscular system due to G-forces and vibration.

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