ORIGINAL ARTICLE

Reactivity, stability, and strength performance capacity in motor sports

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Background: Racing drivers require multifaceted cognitive and physical abilities in a multitasking situation. A knowledge of their physical capacities may help to improve fitness and performance.
Objective: To compare reaction time, stability performance capacity, and strength performance capacity of élite racing drivers with those of age-matched, physically active controls.
Methods: Eight élite racing drivers and 10 physically active controls matched for age and weight were tested in a reaction and determination test requiring upper and lower extremity responses to visual and audio cues. Further tests comprised evaluation of one-leg postural stability on a two-dimensional moveable platform, measures of maximum strength performance capacity of the extensors of the leg on a leg press, and a test of force capacity of the arms in a sitting position at a steering wheel. An additional arm endurance test consisted of isometric work at the steering wheel at +30° and −30° where an eccentric threshold load of 30 N.m was applied. Subjects had to hold the end positions above this threshold until exhaustion. Univariate one way analysis of variance ($\alpha = 0.05$) including a Bonferroni adjustment was used to detect group differences between the drivers and controls.
Results: The reaction time of the racing drivers was significantly faster than the controls ($p = 0.004$). The following motor reaction time and reaction times in the multiple determination test did not differ between the groups. No significant differences ($p>0.05$) were found for postural stability, leg extensor strength, or arm strength and endurance.
Conclusions: Racing drivers have faster reaction times than age-matched physically active controls. Further development of motor sport-specific test protocols is suggested. According to the requirements of motor racing, strength and sensorimotor performance capacity can potentially be improved.

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The overall physical capacity of élite racing drivers is not known. This lack of data is mainly due to the under use of sports medicine and exercise science expertise in this type of sport.[1]

Research in motor sport has found that $V\text{O}_2$ and heart rate response can reach 45–81% of values obtained in a maximal graded exercise test. Psychological stress can have a large effect on metabolic responses.[2 3] Increased fitness has been concluded to lead to reduced cardiological, circulatory, and metabolic responses to the physical and psychological stress experienced in motor sport.[4]

Technical advances in racing car construction as well as changes in track layout have considerably reduced the risk of accidents and serious injury.[5] Direct trauma and other life-threatening injuries are rarely seen, but as racing cars have become increasingly rigid, there is still a high incidence of concussion.[6] Direct trauma mainly affects the head, neck, and legs of racing drivers.[7] The continuing development of safety equipment such as the head and neck support (HANS device) is reducing the incidence of serious injury resulting from accidents.[6] Experience, skill level, and training are thought to be positively related to injury avoidance.[8]

Overuse injuries caused by vibration of the racing car are motor sport-specific and result mainly in musculoskeletal disorders.[9] The mechanisms by which vibration exposure account for musculoskeletal disorders in motor racing are similar to those in other work places.[9 10] The driver requires sufficient strength, especially under fatiguing conditions (muscular endurance), to achieve the high pedal forces in braking procedures (about 600–700 N in GT (Grand Touring) sports car racing) and to stabilise the body and extremities against the high mediolateral and anterior-posterior *g* forces generated.[2]

A closer look at the situation in the car underlines the importance of strength and sensorimotor competence in decreasing the risk of overuse injury. In long-distance racing, two or even up to four drivers share one car. Every driver competes for periods of 1–1.5 hours until refuelling and/or tyre change is necessary. This requires all drivers to share one seat. The drivers are fastened to the seat with six-point safety belts, where a back and forth adjustment is possible, but no adjustment of the back can be made during competition. The size of the "biggest" driver determines the seat settings, and a "small" driver will probably have to work harder to maintain stability of the trunk and legs. Furthermore, because of optimisation of the centre of gravity of the car, the steering wheel, seat, and pedals are not aligned correctly in an ergonomic sense.

Furthermore, sequential gear boxes allow an upward shift without use of a pedal. In downward shifts, the left leg has to be used for the clutch, while at the same time the right leg is performing braking and heel-and-toe throttle on two pedals (brake and throttle). This is a highly coordinated skill requiring well established sensorimotor control and stability work by the legs.

As conditioning training for racing drivers becomes more common, musculoskeletal disorders and overuse injuries may also be caused by intensive exercise as well as the driving. Physical activity in various forms can lead to overuse symptoms.[11] Drivers preparing for competition with strength, endurance, or sensorimotor training may suffer overuse injuries, which may counteract the positive goals of preventive training.

Therefore enhancement of sensorimotor performance and neuromuscular control may be beneficial in the prevention of these kinds of overuse injuries. Clear evidence on ways of preventing soft tissue injury is still lacking, but appropriate training loads and intensities seem to be sensible for controlling the risk of injury and overuse symptoms.[12 13]

In consequence, to prevent both direct trauma and musculoskeletal injury, sophisticated coordinative skills, high reaction speeds, excellent and well established sensorimotor strategies, and adequate neuromuscular control are integral qualities required by racing drivers.[7]

Evaluation of each of these factors may enhance not only the drivers' performance but also their training regimens. Therefore, the purpose of this study was to analyse the fitness of élite racing drivers with regard to reaction time, stability performance capacity, and strength performance capacity.

METHODS

Subjects

Eight racing drivers (the complete 2005 factory driving squad of the Dr Ing hc F Porsche AG) competing in the sports car endurance race series (American Le Mans Series, Grand American Rolex Sports Car Series, FIA-GT Championship Series) and single long-distance races (24 hour Le Mans, 24 hour Nürburgring Nordschleife) in GT racing cars (Porsche 911 GT3 RSR) participated in this study. Ten age-matched subjects involved in recreational sports activity (three hours a week; endurance training and overall conditioning) and considered physically active according to the guidelines of the American College of Sports Medicine, served as a control group (table 1).[14] All control subjects had possessed a driving license, a motorcycle license, or both since the age of 18. They drove on a regular basis but none worked as a professional driver. The major sports disciplines of the control subjects varied from endurance type sports (running, cycling, swimming) to team sports (basketball, soccer). All subjects agreed to take part in the study voluntarily and signed an informed consent statement conforming to the principles outlined in the Declaration of Helsinki.[15] The study was approved by the ethics commission of the local university. All subjects were free of injury and reported no health problems. Before the study, an internal medical and orthopaedic check up confirmed that all the subjects were fit enough to participate in the test protocol.

Measurement protocol

Overall testing procedure

The test protocol started with the testing of cognitive abilities (reaction time) on the Vienna Reaction Apparatus.[16] After a five minute break, postural stability was tested on an unstable platform. A 10 minute warm up on a treadmill (Cosmos; Quasar, Nussdorf-Traunstein, Germany; speed 9 km/h) preceded the force capacity testing.

Reaction time

In the "go/no go" condition of the Vienna Reaction Apparatus (Wiener Reaktionstest RT, version S4), combinations of target stimuli (yellow and red light on the screen) were presented among irrelevant visual (red light only, yellow light only) and audio stimuli that had to be ignored.

Table 1 Anthropometric data for the racing drivers and controls

Group	Age (years)	Weight (kg)	Height (m)	BMI (kg/m^2)
Controls	26.2 (6)	72.7 (7.5)	1.81 (0.08)	22.1 (2.0)
Drivers	26.5 (5)	68.8 (7.8)	1.77 (0.04)	22.0 (1.3)

Values are mean (SD).
BMI, Body mass index.

The median reaction time in milliseconds (visual stimulus to reaction) as well as the motor reaction time (reaction to confirmation) were calculated and used as a measure of reaction time.

Reactive capacity was also measured with the Vienna Reaction Apparatus (Wiener Determinationstest DT, version S12; Meidlinger Form E) where different coloured visual stimuli on the screen had to be confirmed with hand buttons and foot pedals. Median reaction time in milliseconds was also recorded. The determination test (DT) is accepted as a reliable tool for testing reactive capacity over time (test duration 15 minutes) in a complex multiple stimuli reaction test.[16]

Stability

Postural stability performance was tested on a two-dimensional free moving platform (Posturomed; Haider Bioswing, Pullenreuth, Germany). After familiarisation with the test device, each subject was asked to perform unilateral exercises (five left, five right, randomised) with eyes open and hands akimbo. The platform was moved out of equilibrium by 2.5 cm in a lateral direction. After visual control of a stable one leg stand by the investigator, the platform was randomly released by an electromagnet and subjects had to stabilise movement of the platform for a measurement time of 15 seconds. The mean combined deviation of the platform in both dimensions (mediolateral and anterior-posterior) for each leg was measured in centimetres. The mean of the left and right legs served as the measure of stability performance.[17]

Strength performance capacity

For all strength performance capacity tests, subjects warmed up as described above and were verbally encouraged to perform with maximum effort. Strength performance capacity was measured in three randomly assigned test conditions (randomisation of test, work mode, and movement direction) using a CON-TREX LP linear leg press for lower extremity testing, and a CON-TREX MJ multi-joint system with an adapted steering wheel device for upper extremity testing (CMV AG, Dübendorf, Switzerland).

On the leg press, leg extension was measured at 60°/s in isokinetic mode (concentric and eccentric), alternating the legs. Mean peak force (N) out of five trials was calculated for each movement and work mode. Range of motion was set from 10° to 90° knee flexion.

To simulate arm workloads close to real racing driving, subjects were placed on the multi-joint module in a seated position similar to the racing position with both hands on a steering wheel device (MOMO, Milano, Italy; diameter 34 cm). One test comprised isokinetic work at 60°/s in concentric and eccentric mode in a range of motion of 60° (30)° rotation to the left (counterclockwise) and 30° rotation to the right (clockwise). Mean peak torque (N.m) was calculated out of five trials for each mode. An average of clockwise and counterclockwise was calculated.

Strength endurance capacity

In a final test, isometric work was tested in the positions 30° counterclockwise and 30° clockwise. Subjects had to hold the two positions with a threshold load of $\geq$30 N.m until exhaustion. Time until exhaustion in seconds (peak torque value $<$30 N.m) was used as a measure of strength endurance capacity.

Statistical analysis

Descriptive statistical analysis was performed with means and 95% confidence intervals. Differences between the drivers and controls were determined by univariate one way analysis of variance ($\alpha = 0.05$) with the software package JMP 5.01 (SAS Institute, Cary, North Carolina, USA). A Bonferroni adjustment to account for multiple testing was performed by lowering the α level for each test to 0.005 to reach statistical significance on the overall 5% level.

RESULTS

Reaction time

In the ''go/no go'' condition of the Vienna Reaction Apparatus, simple reaction time was significantly ($p = 0.004$) faster in the drivers (330.8 milliseconds) than the controls (370.4 milliseconds). The following motor reaction lasted 104.1 milliseconds in the drivers compared with 120.7 milliseconds in the control group ($p = 0.18$) (table 2).

The multiple determination tests measured with the same apparatus (DT, version S12 - Meidlinger Form E) showed the same reaction times in response to 540 visual cues. The number of correct reactions was also the same, as well as the number of false reactions. Slightly more reactions than the required 540 were executed in both groups (table 2). The multiple determination test showed no significant differences between the two groups ($p>0.05$).

Stability

One-leg postural stability was no different between the legs in both groups. The calculated mean of three 15 second trials of the left leg and three trials of the right leg showed a cumulative sway distance of the platform of 70.0 cm in the racing drivers and 87.7 cm in the controls ($p = 0.47$) (table 2).

Strength performance capacity and strength endurance capacity

The leg force capacity of the extensors did not differ between the groups in either concentric ($p = 0.73$) or eccentric ($p = 0.45$) mode. Compared with the concentric contraction mode, eccentric performance was 35% higher in the controls and about 40% higher in the drivers (table 3). No differences between legs or arms were observed. The test of arm strength on the steering wheel revealed no differences between clockwise and counterclockwise movements. The two groups showed similar values for maximum concentric ($p = 0.42$) and eccentric ($p = 0.68$) mode as well as for strength endurance capacity testing in isometric mode ($p = 0.31$). Here, eccentric work also resulted in higher values compared with concentric contraction (drivers, +43%; controls, +46%) (table 3).

DISCUSSION

The élite racing drivers exhibited faster reaction times than the anthropometrically matched physically active controls. However, their motor responses were no different from the controls. Faster reaction times may reflect a predisposition for motor sports, where fast reaction times are essential, indicating a selection criterion for motor sports athletes. Therefore reaction time may be used as a screening tool for recruiting. On the other hand, racing drivers may have faster reaction times as a result of training. They are having to react at high speeds on a regular basis and therefore reaction time may be enhanced. This potential training effect is doubtful as it is debatable whether simple reaction time can be increased by training. Kida *et al*[18] reported faster reaction times in skilled athletes (baseball, tennis) compared with less skilled players or controls. A longitudinal study did not improve simple reaction time but did enhance skill-specific, decision-making reaction time in baseball hitters. Therefore the test situation probably reflects a basic ability rather an ability improved by training.[18]

Reaction time is used in cognition and neuropsychological assessments in patients to assess outcome after concussion.[19] Reaction time assessment could therefore be used to assess cognitive impairment after an accident. Return to racing decisions could be made by comparing data with baseline values.[19 20]

Similar performances were achieved in the drivers and controls in the multiple determination test. This may indicate the inability of the test used to differentiate between the two groups. Beside the inherent validity of the test, it is questionable whether it can substantially evaluate cognitive function and its change during repetitive one hour periods of driving. Considering the high demand for information processing during racing driving, it is logical to attempt to improve this in motor sport athletes. However, trainability of this function, valid evaluation of any improvement with the

Table 2 Reaction tests and postural stability for controls and racing drivers

			95% Confidence limits	
Test	Mean	SD	Lower	Upper
RT reaction time (ms)				
Controls	370.4	28.9	349.7	391.1
Drivers	330.8	20.3	313.8	347.7
RT motor reaction time (ms)				
Controls	120.7	24.0	102.2	139.1
Drivers	104.1	24.5	83.6	124.7
DT reaction time (ms)				
Controls	649.0	57.4	607.9	690.1
Drivers	637.5	48.0	597.3	677.6
DT correct reactions				
Controls	532.7	7.7	527.2	538.2
Drivers	530.3	10.4	521.5	538.9
DT false reactions				
Controls	14.9	15.2	4.0	25.8
Drivers	12.9	6.2	7.7	18.1
DT overall reactions				
Controls	547.6	9.3	540.9	554.3
Drivers	543.1	14.3	531.2	555.1
Postural stability (cm)				
Controls	87.7	54.6	48.6	126.8
Drivers	70.0	46.5	31.1	108.9

RT, Wiener Reaktionstest, version S4; DT, Wiener Determinationstest, version S12; Meidlinger Form E.

Table 3 Results of force capacity testing for controls and racing drivers

Test	Mean	SD	95% Confidence limits Lower	95% Confidence limits Upper
Leg extensor force (N)				
Concentric				
Controls	1561	161	1412	1709
Drivers	1517	285	1253	1781
Eccentric				
Controls	2072	477	1631	2513
Drivers	2271	466	1840	2702
Arm strength (N.m)				
Concentric				
Controls	75	9	66	84
Drivers	80	11	70	90
Eccentric				
Controls	117	17	102	133
Drivers	114	16	98	129
Arm endurance* (s)				
Controls	94	26	61	127
Drivers	78	27	54	100

*Isometric, threshold of 30 N.m.

test presented, and transfer to driving performance must be questioned. A test and training procedure that is more similar to actual racing driving is necessary for successful transfer to competition.[21] In training and qualifying sessions, where driving of only one fast lap is required, cognitive factors seem to be more important for performance than physical factors. Physical factors come into play more with an increase in the duration of competition.

Reaction time is thought to be related to postural stability or functional measures of balance.[22] The racing drivers and controls in this study did not differ in postural stability. Sensorimotor competence would seem to be crucial to resist *g* forces in the car and therefore beneficial in the prevention of musculoskeletal injuries from vibration. Positive training effects on postural stability by sensorimotor training have been reported in training studies.[23] Therefore, it is worth implementing proprioceptive exercises to increase sensorimotor ability in the overall conditioning programme of racing drivers. The testing of postural stability as a functional outcome of sensorimotor competence of the trunk and legs is widely accepted, and therefore the test could be used to monitor training interventions.[13 22]

The racing drivers in this study exhibited similar maximum force and muscular endurance capacities to the physically active controls. This is in contrast with a previous report of greater strength performances of racing drivers than control subjects.[24] In the latter study, rally drivers performed better with regard to ankle plantar and shoulder flexion than controls and open-wheel drivers (drivers of single seater or formula cars). Open-wheel drivers on the other hand exhibited greater lateral flexion strength of the neck.[24] This suggests a better training status as the result of rally or open-wheel driving (training through competition) which leads to motor sport discipline-specific adaptations. Furthermore it may also represent a better training regimen in rally drivers compared with controls (and in arm and leg strength in rally drivers compared with open-wheel drivers). Although the test batteries and control groups were different from our study, drivers in long-distance races can be considered to have the same strength performance capacity as open-wheel drivers. To judge if the strength level is sufficient for the sport-specific demand, the validity of the testing procedures needs to be stressed. From a methodological point of view, it could be questioned whether the peak force test batteries with movement velocity used can fully represent motor sport-specific demands. Therefore, in addition to maximum tests, other force capacity tests, such as the endurance protocol presented here, should be developed to achieve greater task specificity. Maximum force capacity determines other force dimensions, and therefore peak torque and maximum force seem reasonable quantities to assess.[25] However, task specificity should be considered in the ''strength-endurance continuum''.[26] Training recommendations drawn from the results obtained should be made bearing in mind the limitations of the tests.

In long-distance racing, meticulous preparation to meet the demands of 24 hour competition is logical. The set up in a 24 hour race, as outlined in the introduction, results in an overall race time of eight hours for each driver. Many braking actions have to be executed during those eight hours. If in a single lap there are 15 turns with the preceding braking actions, and each lap lasts two minutes, the driver is required to perform 450 braking manoeuvres in one hour and 3600 in eight hours. A force of 600–700 N per braking action results in an overall load of up to 250 tons. This emphasises the necessity of well established maximum force and muscular endurance capacity. The results indicate either the development potential of strength performance capacity training in long-distance racing drivers or that the strength of these drivers is already at a level sufficient for the task. Of course, if drivers can compete at their present strength level, the question arises why should they exercise more or in a particular way? Training recommendations should always be based on defined goals. If the goal is to increase sport-specific strength levels above those of physically active controls (to lower the risk of injury, to delay the onset of fatigue, and to reduce the load on passive structures), the following frameset should be kept in mind. Force capacity demands in motor sports, resulting from horizontal *g* forces in the anterior-posterior direction, the mediolateral direction, and from repetitive braking are very distinctive. These abilities can be enhanced not only by typical strength training (hypertrophy training) but also by focusing on explosive strength qualities such as the rate of force development, which can be improved by sensorimotor training and can be accompanied by plyometrics or eccentric exercises.[23 27] The ability to generate high muscular strength within short time periods is likely to be desirable in motor sports, where absolute strength performance is probably not crucial. In addition, traditional training with the goal of muscle hypertrophy counteracts optimal body weight strategies, which eventually reduces performance.

What is already known on this topic

- Racing driving requires multifaceted physical and cognitive abilities.
- Cardiovascular responses while driving can reach levels of 60–85% of maximum values.
- Little is known about cognitive, stability, and strength performance capacities of racing drivers.

What this study adds

- Reactive, stability, and strength performance capacities of racing drivers and physically active controls were analysed and compared.
- Except for reaction time, all physical measures in the racing drivers showed no difference from the controls.
- The data can serve as a baseline from which to start training racing drivers.

Increasing strength and stability not only guarantees quick recovery during competition (prolonged competition) but also throughout the training process (from training session to training session). Moreover good physical fitness is a key factor in the prevention of musculoskeletal injury of racing drivers, as training loads in fitness training will increase with further development of this sports discipline.

It was not part of the study to assess aerobic performance of the study cohort, but it should be pointed out that aerobic fitness is a key factor in sustaining increasing training loads, to guarantee recovery and withstand physical stress while driving.[2 8] Finally, attention should be directed to the relation between cognitive factors, strength performance capacity, sensorimotor capacity, and aerobic fitness to develop testing and training regimens that balance all factors to account for the multifaceted physical demands of racing driving.

CONCLUSIONS

Because of the high physical demands of motor sports, systematic testing programmes and training regimens integrating the motor sport-specific physical requirements need to be developed.[28] Initially, procedures for testing physical factors that more closely represent long-distance racing driving need to be established, although reproducing racing conditions in a laboratory will be difficult.

The present results give an idea where to start in fitness training for motor sport athletes, but training recommendations at this point can only be made on a general basis. The demands of long-distance racing driving are such that focus should be on intermuscular and intramuscular coordination as well as sensorimotor performance optimising neural adaptation. Muscle hypertrophy should be avoided so as not to augment body weight. Prospective studies are required to validate the effectiveness of any training techniques devised.

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COMMENTARY

This paper contributes nicely to the field of motor sport by integrating cognitive and physical factors. Clearly motor sport is a multidimensional activity with great emphasis on physical and mental/emotional areas. Investigating both of these with such closely matched controls has produced some interesting results. Of particular note is the finding that the physical components assessed were not significantly different from those of the controls, but reaction times were. My guess, however, is that, within most training regimens prescribed for motor sport athletes, the emphasis is on physical components. Therefore, this study provides an interesting challenge to the growing body of sport science literature that is forming the basis for developing training programmes in this sport.

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