Acta Orthop. Belg., 2017, **83**, 512-520

ORIGINAL STUDY

Acute Injuries Sustained by Racing Drivers: A Cross-Sectional Study

Christos Koutras, Stavros A. Antoniou, Marcus Jäger, Hansjoerg Heep

From the department of Orthopedics in the University Hospital of Essen in Germany

Aim of the present study was to investigate the prevalence and type of acute injuries sustained by 137 racing drivers. An ad hoc questionnaire was developed and was completed by 137 drivers with a mean age (SD) of 42 (15) years. Approximately half of the drivers had < 10 years of experience in auto racing (49%). Multiple logistic regression analyses were performed. There was a wide distribution of injuries of the knee (n=17, 12%), shoulder injuries (n=15, 11%), thorax/rib or ankle (n=13, 9%), hand (n=11, 8%), forearm (n=9, 7%) and neck or wrist injuries (n=7, 5%). Long-distance racing, more than 10 days per month spent on testing, short-distance racing, and full-time occupation were associated with increased incidence of injuries on multivariable analyses. The high incidence of acute injuries in race car driving indicates the need for further improvements.

Keywords : motor sports ; injuries ; athletic injuries ; fractures ; bone ; amateur ; prevention ; orthopedics.

INTRODUCTION

The rapid technical developments in automobile racing sports along with the delayed improvement of safety measures have a great impact on the injuries sustained by racing drivers. Several academic medical studies *(2,3,6,10,11,14)* are dealing with the continuous exposure of racers' bones and muscles to such forces over the years and the effects on their health. The academic literature from the last decade lacks of studies related to injuries in professional and amateur racing drivers.

A prospective study by Minoyama and Tsuchida *(12)* was carried out at Fuji Speedway between 1996 and 2000 and documented the musculoskeletal injuries sustained by 1030 single seat car drivers and 1577 saloon car drivers. A study by Steele (1994) evaluated 57 drivers after accidents, which occurred in 61 open-wheel races. Furthermore, a study by Ebben and Suchomel *(4)* investigated the physical demands, injuries and fitness practices of stock car drivers. Finally, a study by Leonard et al. *(8)* presented the injuries sustained by racing drivers during the period between 2000 and 2002 after a circuit change. The common point of the abovementioned studies is the description of musculoskeletal injuries during different types of racing. Nevertheless, specific information about the kind of injuries and the anatomical localization are not provided.

■ Christos Koutras MD, MHCM, PhD[1].
■ Stavros A. Antoniou MD, PhD[2,3].
■ Marcus Jäger MD, PhD[1].
■ Hansjörg Heep MD, PhD[1].
[1]*Department of Orthopaedics and Trauma Surgery, University of Duisburg-Essen, Germany.*
[2]*Center for Minimally Invasive Surgery, Neuwerk Hospital, Mönchengladbach, Germany.*
[3]*Department of General Surgery, University Hospital of Heraklion, University of Crete, Greece.*
Correspondence: Christos Koutras, Skepastou 27, Komotini, 69100, Greece, Tel.: +30 6970213744; Fax: +30 2107245555
E-mail: christos.koutras@gmail.com
© 2018 Acta Orthopaedica Belgica.

No benefits or funds were received in support of this study. The authors report no conflict of interests.

The present study aims to investigate acute injuries sustained by race car drivers and the parameters that influence the type of the resulting injuries.

MATERIALS AND METHODS

This study was approved by the University Duisburg-Essen Institutional Review Board under code: 11-4669, and each participant signed an informed consent.

General Design and Subjects

From March to December 2011, 137 drivers were interviewed (n = 111) by a dedicated investigator or were sent a questionnaire by e-mail, fax, or post (n = 26). All drivers of the latter group responded following personal contact by the senior author. The interviews occurred during 2 races on June 18, 2011 in Hockenheimring and on July 30, 2011 in Nürburgring. Both professional (n=7) and amateur (n=130) drivers were included in the investigation.

Questionnaire

A questionnaire (in English and German) based on the Nordic questionnaire by Kuorinka et al. *(7)* was used to investigate the parameters that influence the type of the resulting injuries. This investigation's questionnaire was developed to be completed under stressful conditions (the questions had to be in multiple choice form and the interviewee had to answer spontaneously), for better handling of the answers (to avoid a false-positive or false-negative answer), and to collect the information needed for this study.

The first page of the questionnaire presented an introduction on the basic goals of the study, followed by the benefits of these studies for the racing community. The impersonal character of the study, the approval by the ethics committee of the Duisburg-Essen University, and the independence from motor sports organizations were also pointed out. On the same page, 2 basic questions were asked regarding the driver's demographics (age and gender).

The questions on the second page focused on the experience within the sport (< 5 years, 5-10 years, 10-15 years, > 15 years) and other issues, such as whether the driver was a professional racer (primary occupation), the type of racing car (formula racing, touring car/grand tourer, cart, rally), whether the subject was competing as a driver or a co-driver, the days per month spent on testing, the number of races per year and the average racing time in hours.

The next page featured a numbered drawing of the human body with a back and front view. The interviewee was instructed to circle the areas that have been injured (racing-related injuries). Furthermore, the participant was asked to describe the type of injury (fracture, ligament rupture or contusion/cut), the location of the injury based on the numbered drawing of the human body and the type of treatment (conservative or surgical treatment).

Statistics

Statistical analyses using the Pearson's chi-square test of independence in SPSS 20.0 (SPSS Inc., Chicago, Illinois, USA) were performed to compare outcomes between groups, and the likelihood ratio test was used to assess the significance of variations. Multiple logistic regression analyses with dependent variables the injuries, fractures, ligament injuries and cuts or contusions sustained by racing drivers (sustained/not sustained) and independent variables various drivers', vehicles' or race circuits' characteristics were performed, if the p-value at any step of the multivariate analysis was lower than 0.1. The points of interest were determined from our statistician in cooperation with the medical research team in order to identify the correlation between the parameters and extract structured data. A value of $P < 0.05$ was considered significant.

RESULTS

In the group of 137 drivers only 4 of them were women. The mean age (SD) among the 131 drivers who provided this information was 42 *(15)* years. The drivers were also asked if their racing activity was a full-time job. For 5%, auto racing was their full-time occupation and the remaining 95% had another primary occupation.

Naamloos-3 513 28/05/18 19:10

The distribution of driving experience within this sample was as follows: 25% of the participants were racing drivers for < 5 years, 24% for 5 to 10 years, 15% for 10 to 15 years, and 36% for > 15 years. Most of the drivers (41%) performed training for < 5 days per month, 40% trained for 5 to 10 days monthly, only 14% trained for 10 to 15 days per month, and 4% trained > 15 days per month. The racing activity was obviously higher: 24% raced < 5 times per season, 13% participated in 5 to 10 races per season, 43% participated in 10 to 15 races, and 19% raced > 15 times per season.

Concerning the type of car driven, 37 drivers were participating in formula racing, 110 in touring car/grand touring, 19 in cart, and 7 in rally. Three of the drivers were racing in 3 different categories and 20 of them in 2 categories. The most common combinations were formula racing and touring car; formula racing and cart; and touring car and cart. The majority of subjects of the study sample consisted of road race drivers (n=131). All the competitors were drivers, except for 1, who also participated in touring car category as a co-driver. Finally, the distribution of type of racing according to the duration of the race within this sample was as follows: 51% of drivers were competing in short-distance races, 17% in mid-distance races, and 52% in long-distance races. (Note: the percentages add up to > 100% because the drivers were competing in more than one category.)

The injuries sustained during racing are summarized in Figure 1. Seventeen drivers (12%) suffered a knee injury, 15 drivers (11%) shoulder injury, 13 drivers (9%) thorax/rib or ankle injury, 11 drivers (8%) hand injury, 9 drivers (7%) forearm injury, and 7 drivers (5%) neck or wrist injury.

Figures 2-4 summarize racing injuries in decreasing severity. The first diagram (Figure 2) presents the number of drivers who sustained fractures, the second (Figure 3) ligament injuries and the last diagram (Figure 4) contusions or cuts.

The conservatively treated rib fracture was the most common injury, followed by the conservatively treated shoulder fracture. The surgically treated ankle and knee fractures, the conservatively treated ligament injuries in ankle and knee region, the surgically treated ligament injuries in the aforementioned anatomical regions and the cuts or contusions of the trunk and upper limb followed.

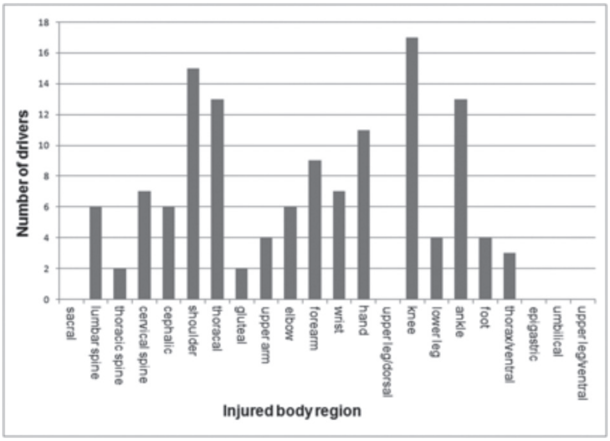

Fig. 1.— Number of drivers who sustained injuries, according to the anatomical region

Cart driving was associated with injuries of the upper arm, elbow, forearm, hand and lower leg region (p<0.05). This type of racing car was associated with conservatively treated fractures of the elbows, forearms and lower legs (p<0.05) Furthermore, an association of cart driving with surgically treated fractures in the lumbar region, surgically treated cuts in the hand region and conservatively treated ligament injuries in the lower legs was evident (p<0.05). Finally, cart driving was associated with conservatively treated contusions or cuts in the lumbar region, elbows, forearms, hands, knees and lower legs (p<0.05).

Rally driving was associated with surgically treated fractures in the cervical spine, ankle region and foot region (p<0.01), and conservatively treated

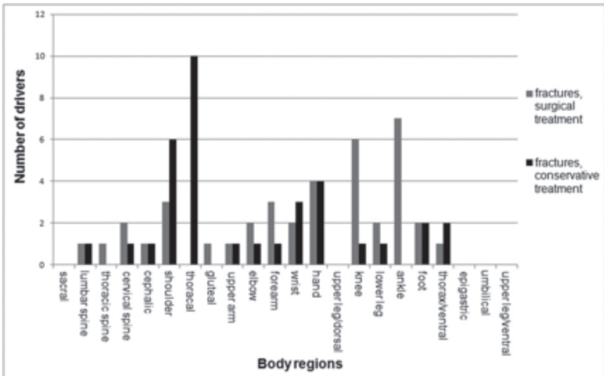

Fig. 2.— Number of drivers who sustained fractures, according to the anatomical region

Naamloos-3 514 28/05/18 19:10

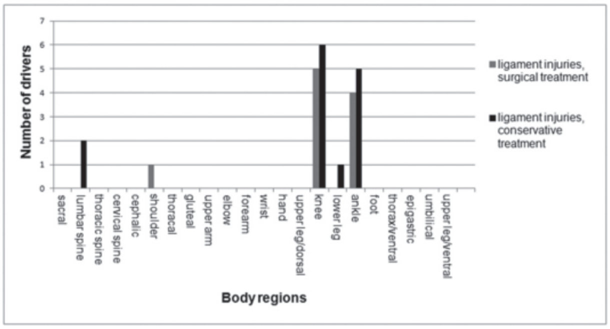

Fig. 3.— Number of drivers who sustained ligament injuries, according to the anatomical region

fractures in knees (p<0.001). Furthermore, there was an association between rally driving and cuts, which were operated in the head and lower leg region (p<0.05), and conservatively treated in the shoulder, thorax, elbow, hand and knee region (p<0.05).

Touring car or grand tourer driving was associated with conservatively treated fractures of the knees (p=0.043), surgically treated cuts of the lower legs (p=0.043) and conservatively treated contusions or cuts of the upper legs, ankle region and upper abdominal region (p<0.05). Outcomes of univariate analyses are summarized in Table I.

A backward multiple logistic regression analysis was performed, removing insignificant independent variables one by one. Two variables were found to independently predict sustained injuries: more than 10 days per month spent on testing (regression coefficient 3.75, 95% confidence interval 1.46-9.65); and long-distance racing (regression coefficient 5.04, 95% confidence interval 1.67-15.21). The fractures sustained by racing drivers were independently predicted by three variables: short-distance racing (regression coefficient 3.22, 95% confidence interval 1.05-9.83), more than 10 days per month spent on testing (regression coefficient 2.93, 95% confidence interval 1.13-7.62); and long-distance racing (regression coefficient 4.90, 95% confidence interval 1.56-15.43). Furthermore, two variables were found to independently predict sustained ligament injuries: full-time occupation (regression coefficient 11.04, 95% confidence interval 1.91-63.89); and long-distance racing (regression coefficient 4.68, 95% confidence interval 1.25-17.47). Finally, one variable was found to predict sustained cuts or contusions: full-time occupation (regression coefficient 5.75, 95% confidence interval 1.69-19.57). Results of logistic regression analyses are presented in Table II.

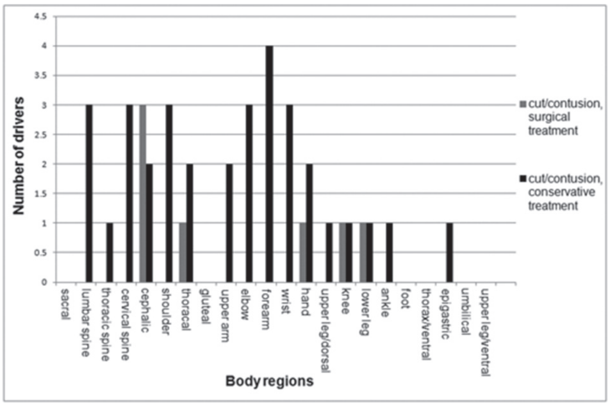

Fig. 4.— Number of drivers who sustained cuts or contusions, according to the anatomical region

DISCUSSION

The present analysis suggests that race car drivers suffer primarily from injuries of the knee, shoulder, thorax and ankle region. Furthermore, the following parameters were associated with increased incidence of injuries on multivariable analyses: long-distance racing, more than 10 days per month spent on testing, short-distance racing, and full-time occupation. The goal of this study was to detect the most common auto racing injuries and their associations with various drivers', vehicles' or race circuits' characteristics, in order to make recommendations for technical improvements and provide the groundwork for potential regulation changes.

The musculoskeletal injuries during racing are documented in the study by Minoyama and Tsuchida *(12)*, which was carried out at Fuji Speedway between 1996 and 2000. In 39 races participated 1030 single seat cars and 1577 saloon cars participated in 42 races. The numbers of injuries for the single seat cars were: neck sprain 17 drivers, bruising (upper limbs) 6 drivers, bruising (lower limbs) 11 drivers, bruising (head) 4 drivers, bruising (chest) 4 drivers, bruising (back) 4 drivers, abrasion (upper limbs) 1 driver, abrasion (lower limbs) 0 drivers, abrasion

Naamloos-3 515 28/05/18 19:10

Table I. — Injuries sustained during auto racing according to the type of racing car, which were statistical significant in univariate analysis

Type of racing car	General or specific type of injury	Anatomical region	Statistical significance
Cart driving	injuries	upper arm	p=0.034
		elbow	p=0.009
		forearm	p=0.006
		hand	p=0.024
		lower leg region	p=0.034
	conservatively treated fractures	elbows	p=0.012
		forearms	p=0.012
		lower legs	p=0.012
	surgically treated fractures	lumbar region	p=0.012
	surgically treated cuts	hand region	p=0.012
	conservatively treated ligament injuries	lower leg region	p=0.012
	conservatively treated contusions or cuts	forearms	p=0.034
		elbows	p=0.007
		lumbar region	p=0.012
		hands	p<0.001
		knees	p=0.012
		lower legs	p=0.012
Rally driving	surgically treated fractures	cervical spine	p=0.004
		ankle region	p=0.001
		foot region	p=0.004
	conservatively treated fractures	knees	p<0.001
	surgically treated cuts	head	p=0.025
		lower leg region	p<0.001
	conservatively treated contusions or cuts	shoulder	p=0.025
		thorax	p=0.004
		elbow	p=0.025
		knee region	p<0.001
		hand	p=0.004
Touring car or grand tourer driving	conservatively treated fractures	knees	p=0.043
	surgically treated cuts	lower legs	p=0.043
	conservatively treated contusions or cuts	upper legs	p=0.043
		ankle region	p=0.043
		upper abdominal region	p=0.043

face 0 drivers, wrist sprain 0 drivers, ankle sprain 1 driver, L1 burst fracture 0 drivers, tibial fracture 0 drivers, bennett fracture 0 drivers, concussion 1 driver, death 1 driver and finally the total number of injured single seat car drivers were 50.

The numbers of injuries for the saloon cars were: neck sprain 33 drivers, bruising (upper limbs) 10 drivers, bruising (lower limbs) 5 drivers, bruising (head) 0 drivers, bruising (chest) 1 driver, bruising (back) 1 driver, abrasion (upper limbs) 1 driver,

Naamloos-3 516 28/05/18 19:10

Table II.— Correlation of injuries, fractures, ligament injuries and cuts or contusions sustained by racing drivers with various drivers', cars' or races' characteristics on multivariate analysis

		Regression coefficient (95% confidence interval)	p-value
Sustained injuries*	Female gender	9.69 (0.94 - 100.25)	0.057
	> 10 days per year testing	3.75 (1.46 - 9.65)	0.006
	Long-distance racing	5.04 (1.67 - 15.21)	0.004
	Short-distance racing	2.85 (0.97 - 8.43)	0.058
Sustained fractures**	> 10 days per year testing	2.93 (1.13 - 7.62)	0.027
	Long-distance racing	4.90 (1.56 - 15.43)	0.007
	Short-distance racing	3.22 (1.05 - 9.83)	0.040
Sustained ligament injuries†	Full-time occupation	11.04 (1.91 - 63.89)	0.007
	Long-distance racing	4.68 (1.25 - 17.47)	0.022
Sustained contusions or cuts‡	Formula racing	0.22 (0.03 - 1.55)	0.128
	Touring car or grand tourer	0.18 (0.02 - 1.39)	0.100
	Cart	5.75 (1.69 - 19.57)	0.005
*Overall likelihood ratio x^2(df = 4) 20.38, p<0.001; Nagelkerke R^2=0.190, Hosmer and Lemeshow Test p=0.851, based on 137 observations			
**Overall likelihood ratio x^2(df = 3) 13.66, p=0.003; Nagelkerke R^2=0.141, Hosmer and Lemeshow Test p=0.239, based on 137 observations			
†Overall likelihood ratio x^2(df = 2) 19.03, p=0.001; Nagelkerke R^2=0.230, Hosmer and Lemeshow Test p=1.000, based on 137 observations			
‡Overall likelihood ratio x^2(df = 3) 8.50, p=0.037; Nagelkerke R^2=0.111, Hosmer and Lemeshow Test p=0.904, based on 137 observations			

abrasion (lower limbs) 1 driver, abrasion face 1 driver, wrist sprain 1 driver, ankle sprain 1 driver, L1 burst fracture 1 driver, tibial fracture 3 drivers, bennett fracture 1 driver, concussion 2 drivers, death 0 drivers and last the total number of injured saloon car drivers were 62. Table III summarizes the abovementioned injuries and presents their respective probabilities.

A direct comparison with our study cannot be conducted, due to differences in car racing type, demographic characteristics etc.. Nevertheless, herein, we would like to present the probability of a body region to get injured during racing. We will only present the probabilities that are common in our study and the study conducted by Minoyama and Tsuchida *(12)*. To that end, the probability for the drivers in our study to suffer from an injury were the following: neck sprain 5% (7/129 injuries), bruising/abrasion (upper limbs) 13% (17/129 injuries), bruising/abrasion (lower limbs)

Naamloos-3 517 28/05/18 19:10

Table III.— Injuries and probability of a body region to get injured during racing as described in the study by Minoyama and Tsuchida (2003)

Injured anatomical region	Single seat car injuries	Single seat car injuries, %	Saloon car injuries	Saloon car injuries, %
Neck sprain	17	34 %	33	53 %
Bruising (upper limbs)	6	12 %	10	16 %
Bruising (lower limbs)	11	22 %	5	8 %
Bruising (head)	4	8 %	0	0 %
Bruising (chest)	4	8 %	1	2 %
Bruising (back)	4	8 %	1	2 %
Abrasion (upper limbs)	1	2 %	1	2 %
Abrasion (lower limbs)	0	0 %	1	2 %
Abrasion face	0	0 %	1	2 %
Wrist sprain	0	0 %	1	2 %
Ankle sprain	1	2 %	1	2 %
L1 burst fracture	0	0 %	1	2 %
Tibial fracture	0	0 %	3	5 %
Bennett fracture	0	0 %	1	2 %
Concussion	1	2 %	2	3 %
Death	1	2 %	0	0 %
Total	50	100 %	62	100 %

3% (4/129 injuries), concussion/ bruising/ abrasion (head) 2% (2/129 injuries), bruising (chest) 0%, bruising (back) 2% (3/129 injuries).

The study by Steele *(13)* was carried out at Indianapolis Raceway Park between 1988 and 1993. 57 drivers were evaluated after accidents, which occurred in 61 open-wheel races. The study aimed at the emergency care during the race, thus it was impossible to extract the injury rate according to the body region. The same applies to several publications concerning emergency medicine approaches in auto racing injuries.

Ebben and Suchomel *(4)* investigated the physical demands, the injuries and fitness practices of stock car drivers. The injuries were evaluated through two open-ended questions, and they were documented according to the anatomical localization and the need for medical care. Specific information about the kind of injuries could not be extracted.

Finally, the study by Leonard et al. *(8)* investigated the role of changing the configuration of a motor racing circuit and presented the injuries sustained by racing drivers in the period between 2000 and 2002, after the circuit change. The total number of injured drivers was 130 out of 6090, 10 of them were referred to hospital with minor injuries, 2 with moderate injuries and 2 with major injuries. Once again the data were not presented in detail and could not be compared to the data of our study.

The injury rate and trauma severity could be reduced through lowering the average speed of the racing vehicles. The most common ways to reduce the mean racing speed are the following: reduction of power of the engine (reduction of capacity and/or cylinder count) reduction of aerodynamic downforce, changes of the track configuration (e.g. chicane placement by circuit designers), reduction of the mechanical grip of the tires (e.g. by reducing

Naamloos-3 518 28/05/18 19:10

the contact area) and restrictions for the suspension system and electronic aids. Another way of reducing serious injuries is through improved protection measures such as: impact-absorbing structures for the racing vehicle and the crash barriers, and protective clothing. Special attention should be given to professional drivers, long-distance drivers, individuals who spent more than 10 days per month on testing and short-distance drivers. An excellent example of effective protecting equipment is the HANS device (Head and Neck Support device) introduced in 2003 in Formula One, a device which should be mandatory in all racing classes. The low rate of injuries in cervical spine in our study may be due to the introduction of HANS (obligatory or not, in different time points and racing categories). Such an association cannot be suggested by the present study, due to its cross-sectional design. The improvements of safety in racing in touring car racing vary among numerous categories of professional and amateur sport, throughout the years, and are heterogeneous across countries and at different time points. Only in Formula One the time point of introduction of HANS, such as other protection measures, is clearly defined (2003) and their impact can be further investigated. A recent study by Lippi et al. *(9)* described the impact of changes in technical regulations on drivers' performance in Formula One from 1995 to 2006, which may prove very useful for all racing classes. Finally, two recent publications have shown the importance of track configuration (5,8). In the study by Edwards et al. *(5)* the relative risk of injuries, which required medical care during driving on oval tracks versus road courses, was statistically significantly greater (RR 6.14; $p<0.001$). Likewise, in the study by Leonard et al. (8) the injury rate was reduced from 0.1% to 0.03% ($p<0.05$) after the introduction of two chicanes.

A potential limitation of the present study could be that the auto racing examined in this study is a leisure activity and the drivers were mainly novice drivers. Therefore, it may be supported that the generalization of the results on professional racing drivers would not be appropriate. In addition, in the group of 137 drivers only 4 of them were women, thus limiting the external validity of the outcomes of the present analysis in male drivers. Another restriction could be that our study group did not contain off-road vehicles drivers, which could significantly alter the results of our study (possibly greater injury rate). Moreover, subgroup analyses of the results of injuries sustained in different racing types would not be appropriate, because of the limited sample. Furthermore, 23 drivers were participating in 2 or 3 different racing categories and no driver was exclusively cart driver. The majority of cart drivers were participating in formula racing and/or touring car racing. Thus, it would be inappropriate to suggest that our results are representative of the injuries suffered by cart drivers, and any comparison with similar outcomes in the contemporary literature would not be rational. Furthermore, a direct comparison with the studies by Minoyama and Tsuchida *(12)*, Steele *(13)*, Ebben and Suchomel *(4)* and Leonard et al. *(8)* was not possible, because of different approaches used by the studies. Finally, an important limitation could be the cross-sectional design of the present study. Bowling *(1)* described that the ability to recall adequately an event of minor importance (minor injury in the context of the present work) may be diminished for a period of more than 6 months in the past.

Similar studies have investigated racing car injuries, which were sustained in professional levels. The vast majority of drivers included in our study were amateurs, thereby enriching our knowledge on race car injuries in this broad category of racing car drivers, who represent the vast majority of racing drivers. An important direction for future work is to investigate the performance of novice drivers and how this affects accidents and injuries. Because of reduced experience and training, novice drivers may be involved in more accidents and experience more injuries. However, lower speeds in novice races could reduce accidents and injuries.

CONCLUSION

The present study investigates the acute injuries sustained by racing drivers. The benefits derived from current safety measures and the need for additional protective measures require further investigation.

Naamloos-3 519 28/05/18 19:10

The high incidence of acute injuries in racecar driving indicates the need for further improvements regarding the construction techniques of the race car, driver-oriented equipment, the racing regulations and circuit design, all targeting on higher safety of race cars. Reducing the mechanical grip of the tires (e.g. by reducing the contact area), the power of the engine and the downforce may constitute potentially effective technical improvements.

The findings of the present study may prove very useful for the preparation and the performance of the on-track emergency medical team. Health insurance companies would undoubtedly benefit from the eventual reduction of the injury rate. Furthermore, engineers would find every change challenging and eventually succeed an elimination of the potential worsening of racing performance. Organizing bodies would benefit from the aforementioned safety improvements by eliminating any disadvantageous factors and even in the case of speed reduction the offered spectacle would not be compromised (no anticipated reduction of overtaking). Finally, the study results and the recommendations concerning safety measures may be applicable to commercial drivers, although investigation in this setting is warranted.

REFERENCES

1. **Bowling A.** Research methods in health. McGraw-Hill *Education*: UK, 2014.
2. **Burton AK.** Back pain in Grand Prix drivers. *Br J Sports Med*. 1983; 17: 150-1.
3. **Burton AK, Sandover J.** Back pain in Grand Prix drivers: a ‘found’ experiment. *Appl Ergon.* 1987; 18: 3-8.
4. **Ebben WP, Suchomel TJ.** Physical demands, injuries, and conditioning practices of stock car drivers. *J Strength Cond Res.* 2012 May; 26(5):1188-98. Am Surg. 2009; 75: 857-9.
5. **Edwards MJ, Lewis JD, Pritts TA et al.** Track configuration determines risk of driver injury in open wheel motor racing. *Am Surg.* 2009; 75: 857-9.
6. **Koutras C, Buecking B, Jaeger M, Ruchholtz S, Heep H.** Musculoskeletal injuries in auto racing: a retrospective study of 137 drivers. *Phys Sportsmed*. 2014; 42: 80-6.
7. **Kuorinka I, Jonsson B, Kilbom A et al.** Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. *Appl Ergon.* 1987 ; 18: 233-7.
8. **Leonard L, Lim A, Chesser TJ, Norton SA, Nolan JP.** Does changing the configuration of a motor racing circuit make it safer? *Br J Sports Med.* 2005; 39: 159-61.
9. **Lippi G, Salvagno GL, Franchini M, Guidi GC.** Changes in technical regulations and drivers’ safety in top-class motor sports. *Br J Sports Med*. 2007; 41: 922-5.
10. **Mansfield NJ, Marshall JM.** Symptoms of musculoskeletal disorders in stage rally drivers and co-drivers. *Br J Sports Med.* 2001; 35: 314-20.
11. **Masmejean EH, Chavane H, Chantegret A, Issermann JJ, Alnot JY.** The wrist of the formula 1 driver. *Br J Sports Med.* 1999; 33: 270-3.
12. **Minoyama O, Tsuchida H.** Injuries in professional motor car racing drivers at a racing circuit between 1996 and 2000. *Br J Sports Med.* 2004; 38: 613-6.
13. **Steele AG.** Emergency medical care for open wheel racing events at Indianapolis Raceway Park. *Ann Emerg Med.* 1994; 24: 264-8.
14. **Videman T, Simonen R, Usenius J, Osterman K, Battié M**. The long-term effects of rally driving on spinal pathology. *Clin Biomech* (Bristol, Avon). 2000; 15: 83-6.

Naamloos-3 520 28/05/18 19:10