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Physical Demands, Injuries, and Conditioning Practices of Stock Car Drivers

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Abstract

Ebben, WP, and Suchomel, TJ. Physical demands, injuries, and conditioning practices of stock car drivers. *J Strength Cond Res* 26(5): 1188–1198, 2012–The purpose of this study was to assess the physical demands, injuries, and conditioning practices of stock car drivers. Forty stock car drivers from 27 states in the United States participated in the interviews for 43.9 ± 13.9 minutes. The interviews examined background information, the physical demands of racing, injuries associated with racing, and the athletic and fitness background and practices of the subjects. Numerical data were analyzed using Pearson's correlation coefficients. Responses to open-ended questions were analyzed using inductive content analysis. Results revealed significant correlation between track points standings and the length of the resistance training sessions ($R = -0.71$, $p = 0.002$) and subject self-assessment of their fitness ($R = -0.53$, $p = 0.045$). Results also revealed that ''upper-body strength'' was identified as the most important physical demand. Extreme fatigue was the most common feeling after a demanding race. Subjects reported that shoulder fatigue was the most common form of muscle soreness experienced after a race. Back and torso injuries were the most common injury, although head injuries most frequently required medical attention. The subjects' biggest fear was fire, followed closely by head and neck injury. The bench press and running were the most commonly performed resistance training and cardiovascular exercises, respectively. Subjects reported that their highest motivation for training was to improve their racing performance. Many subjects had athletic backgrounds with football identified as the sport they had most commonly participated in. This study provides additional detailed information. Results of this study can assist strength and conditioning professionals in the development of strength and conditioning programs for performance enhancement and injury prevention that are specific to the needs of this population of athletes.

Key Words needs analysis, program design, strength, endurance, racing

Introduction

Stock car racing is one of the largest spectator sports in the United States (14). Articles on driver fitness have appeared in popular consumer publications (22) and the racing literature (20). Recently, strength and conditioning practices have been recommended for stock car drivers (10). Although stock car drivers require athletic abilities and experience injuries, the physical demands, injuries, and training practices have not been researched with this population of athletes (10).

Research has yet to examine the physical demands and physiology of stock car racing (6). Nonetheless, a number of studies have evaluated some of these issues with open wheel formula car racing (1,15,16,19,26) and other types of racing such as "national class" (27) and sports cars (3). These studies show that some race car drivers demonstrate heart rates, $\dot{V}O_2$, ventilatory volumes, and metabolic response that are similar to those of athletes participating in basketball, boxing, soccer, running, bicycling, and handball (15,16). Heart rates responses range from 142 to 180 $b \cdot min^{-1}$ (16,19) with energy expenditures that are 8–10 times greater than resting levels while driving in nonracing high-speed conditions in open wheel cars (15).

Driving a race car also appears to require substantial strength. Race car drivers demonstrate trunk flexion and extension force production, leg extension strength, and neck extension strength that is similar to a variety of other athletes (1). Racing also requires the ability to control multiplaner acceleration of the torso, neck, and head and react to acute visual stimuli such as another driver and accidents on the track (1,3,13,19,27). Race car drivers demonstrate better reaction time than controls (3) and superior hand, ankle, trunk, neck, grip, and leg extensor strength compared with

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Table 1. Physical demands of driving a stock car (N = 40).*

Main concept	No.†	Secondary concept	No.†	Select quotes representing responses to this question
Upper-body strength	40	Upper-body strength, general	20	Upper-body strength especially if you lose power steering box, pretty intense
		Arm strength	13	Arms wore out by the end of the race; arms feel like they are going to fall off early in the season
		Hand grip strength, steering	7	Hands, especially when tires rub; hands feel like they are going to fall off early in the season
Cardiovascular endurance	25	Aerobic endurance	19	To try to keep your HR down and stay calm; need to be in good aerobic shape during longer races
		Stamina	6	Exhaustion and fatigue
Heat tolerance	18	Heat tolerance	18	Need to handle the heat to keep composure; 140° in the car; lose 5 kg a race
Neck and core issues	15	Neck muscles/strength	15	Need neck strength because of "G"-forces and collision
		Back pain/soreness	4	I have back pain and soreness
Lower-body strength	13	Legs	10	On and off the gas and breaks, it's like working out in a gym; I push that break as hard as I can
		Calf strength	3	Calf fatigue from breaking
Horizontal acceleration	10	G-forces, general	7	Cornering G-forces put you into the side of the car
		Core strength to cope with G-forces	2	Need a strong core to deal with G-forces
		Leg strength to cope with G-forces	1	G-forces push leg to the outside of the car
		G-forces on neck	1	G-forces on neck
Other	8	Other	8	Muscle cramps, dirt under contact lenses, mouth gets tired, noise, butt hurts

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†The number of study participants whose answers are included in this category.

controls (1). Thus, these physical attributes seem necessary for success when driving some types of race cars.

Research identifying stock car racing injuries is limited and dated with one study examining the hospitalization of drivers as a result of racing injuries. This study identified 31 extremity injuries, 22 contusions, 12 strains, 12 knee injuries, and 11 fractures (5). Other published reports identify a variety of concerns such as head acceleration during crashes and the associated head and neck injuries (11,23), heat stroke (19), and back and cervical spine pain because of stiff race car suspensions, down force characteristic of race cars, and seats with limited padding (4).

Physical fitness is believed to be important for race car driving performance (18,26) and may affect racing safety and competitive pace (15,16). The development of sound strength and conditioning programs requires a comprehensive needs analysis (2). This analysis includes consideration of the demands of the sport, the injuries that occur, and the training practices and training status of its participants (2). Most of the limited published racing research is dated and focuses on open wheel formula car racing outside the United States. To date, no research has examined these issues with stock car drivers. The purpose of this study was to assess the physical demands, injuries, and training practices of stock car drivers to further understand this sport and its participants and to provide information to guide the strength and conditioning professional who works with this population of athletes.

Methods

Experimental Approach to the Problem

This study was designed to test the hypothesis that stock car drivers experience a variety of physical demands similar to those that have been proposed for other forms of automobile racing, that stock car driver experience a variety of injuries, and that the strength and conditioning practices of these subjects are correlated to their racing performance. For the quantitative elements of the study, the independent variables included the quantification of exercise participation. The dependent variables included racing success as measured by track points standings.

Table 2. Stock car drivers' response to the question "What other performance abilities are required for racing?" (N = 40).*

Main concept	No.†	Secondary concept	No.†	Select quotes representing responses to this question
Mental skills	26	Mental strength	12	Mental conditioning is huge; you have to be mentally fit; need to keep sharp, lots of head games
		Focus	9	Stay focused and keep my head straight; diversify attention between track, gauges, and flagman
		Anticipation	6	Anticipate what is about to develop, thinking ahead to avoid wrecks
		Judgment	2	You need to have good judgment out there
		Calmness	2	You have to stay calm
Vision	14	Depth perception	8	Judge distances, looking past the nose of your car and judging distance
		Vision	3	Good field of vision, eye scanning, good peripheral vision
Coordination	12	Hand/foot/eye coordination	12	Hand eye coordination, hand foot coordination
		Fine motor skills	2	Need to be smooth with your driving
Reflexes/reaction	9	Reflexes/reaction	9	Quick reflexes, need fast reaction time
Tactile feel for car	5	Tactile feel for car	5	Back and butt feel what is going on in the car
Other	7	Other	7	Make sure to breath; seat position, you need to be comfortable; hydration

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†The number of study participants whose answers are included in this category.

Table 3. Stock car driver's response to the question, "How do you feel physically after a physically demanding race?" (N = 40).*

Main concept	No.†	Secondary concept	No.†	Select quotes representing responses to this question
Fatigue	36	General extreme fatigue	16	Absolutely exhausted, especially after longer races; drained; spent; feel like you have run a marathon
		General fatigue	9	Worn out a little; 75 laps races are pretty demanding; feel like running a 5-km race; almost exhausted
		Lower-body fatigue	9	Didn't have enough strength to walk, need to sit down, fell over, legs are done
		Upper-body fatigue	7	Dirt gets rough and steering gets jerked around; arms feel really heavy
Thirst/perspiration	26	Thirst	12	Very thirsty
		Perspiration	8	Wet form head to toe, sweating bullets
		Hot	6	Hot; heat bothers me as I get older
Cardiorespiratory effects	9	Elevated HR	5	Heart rate is high
		Shortness of breath	4	Breathing is hard; have to remember to breathe; hard to catch my breath
Feel good	3	Feel good	3	I stay in shape, so I feel good
Other	3	Other	3	You can get dirt in your eyes, under your contact lenses, stomach aches from the stress; cramps

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Table 4. Stock car driver's response to the question, ''do you experience muscle soreness after racing?'' (N = 40).*

Main concept	No.†	Secondary concept	No.†	Select quotes representing responses to this question
Upper body	34	Shoulder fatigue	10	Right shoulder goes up and left down from steering, gets tired
		Arms soreness	9	Arms lock up and cramp; arms are sore
		Cramps	5	My forearms and hand cramps
		Hands fatigue/soreness	5	Hands are tired from gripping the wheel
		Shoulders soreness	3	Shoulders are sore
		Chest bruised/sore	2	Right side chest is bruised from the seat
		Upper-body soreness, general	1	Upper-body sore from tensing up
		Arm bruises	1	Seat bruises my left arm
Core/torso	17	Rib pain/soreness	9	Bruised ribs; ribs get sore from all the pounding
		Back pain/soreness	5	Upper back is sore
		Bruised from harness	2	Especially from belts
		Stomach ache	1	Stomach aches from pounding and emotional stress
Head/neck	14	Neck soreness	10	Neck sore especially if the seat is not adjusted right
		Headaches	3	Headaches from all the pounding
		Head and neck restraint discomfort	1	HANS digging into my collarbone
Lower body	11	Leg soreness	6	Legs hurt, can hardly walk; left leg fatigues from pushing the breaks
		Lower leg cramping	5	Calf cramp from breaking
		Ankle fatigue	1	Ankle from working the clutch and break
Soreness after an accident	9	Soreness after an accident	9	Sore from accidents, especially after a wreck
Other	8	Other	8	Pulled muscles, tingling, sore early in the season, more sore the next day
None	3	None	3	No, I stay fit, you got to be fit

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Subjects

Forty stock car drivers (age = 35.91 ± 13.4 years; height 178.51 ± 7.39 cm; weight 86.20 ± 16.67 kg; racing experience = 13.58 ± 11.30 years; age at start of their racing career = 21.39 ± 9.53 years) from 27 states in the United States participated in this study, via telephone or in person interviews. Twenty subjects raced on dirt tracks, and 20 subjects raced on asphalt tracks. Two subjects raced on both dirt and asphalt. Subjects participated in a variety of classes of racing. Eighteen subjects raced late model or super late model stock cars, 8 raced in a modified class, 6 raced sportsmen or super stock, 6 raced street stock, 2 competed in front wheel drive cars, and 1 competed in the Craftsman Truck Series. Collectively, these drivers estimated that the average cost of stock cars in the division that they race was $29,140.65. Ten of these drivers were nationally ranked by various racing governing/sanctioning bodies, with an average ranking in the top 21%. Ten drivers were regionally ranked with their average ranking in the top 11%. Collectively, the drivers ranked in the top 24% at the specific race tracks they raced at. Institutional review board approval was acquired for the project and informed consent were obtained from the subjects.

Procedures

The "Stock Car Driver Survey" was created and was pilot tested with an advisory group of strength and conditioning specialists, sport scientists, and stock car drivers. The survey was divided into 6 sections including background information, physical demands, injuries, fitness practices, psychological demand, and miscellaneous. The data presented in this article include the background information, physical demands, injuries, and fitness practices of the subjects.

The subject sample was obtained from a variety of sources via the Internet. From this information, a list of subjects and their contact information were compiled. Subjects were then selected at random, from this list, and sent an introductory e-mail letter describing the project. The purpose of the introductory e-mail was to explain the project, the expected time commitment, and the confidentiality of information.

Table 5. Stock car driver's response to the question "Please identify any racing-related injuries that you have had?" (N = 40).*

Main concept	No.†	Secondary concept	No.†	Select quotes representing responses to this question
Back/torso	18	Back soreness/pain	6	Back pain due to jolts, rolled end over end 3 times
		Bruises	6	Bruising from seat harness, hit elbow
		Back injury, not specific	3	Hurt my back in an accident
		Rib injury	3	Bruised ribs, broken ribs
Upper body	17	Hand injuries	10	Ruptured tendon from steering wheel, broken hand, hands, and knuckles bruised
		Bruises	4	Hit elbow
		Wrist injuries	2	Broken wrist
		Shoulder	1	Dislocated shoulder
Head	13	Concussion	10	Concussion
		Headaches	1	Headaches from carbon monoxide
		Tongue	1	Bit tongue
		Lost consciousness	1	Knocked out
Neck	10	Neck soreness/pain	5	Neck pain
		Neck injury	5	Whiplash
Leg injury	7	Sprained foot/ankle	2	
		Minor burns on feet	2	
		Pulled gluteus maximus	1	
		Pulled hamstring	1	
		Knee joint injury	1	ACL/meniscus tear
Cuts and abrasions not specified	6	Cut	2	Needed stitches
		Abrasions	2	
		Bruises	2	
None	5		5	

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†The number of study participants whose answers are included in this category.

Table 6. Stock car driver's response to the question "Please identify any racing-related injuries that you have required medical attention" (N = 40).*

Main concept	No.†	Secondary concept	No.†	Select quotes representing responses to this question
Treated by EMS at track	27	Head injury	10	Head injury, lost consciousness, concussion
		Limb injury	7	ACL, tendon rupture, dislocated shoulder, broken hand, ankle sprain
		Neck injury	5	Whiplash, neck injury, cut neck
		Torso injury	5	Broken ribs, strained back
Hospitalization	15	Neck injury	5	Neck injury, lacerated neck
		Head injury	5	Concussion, lost consciousness
		Limb injury	3	ACL ligament injury, ruptured tendon
		Torso injury	2	Back injury, broken ribs
None	4	None	4	None
Chiropractor treatment	1	Back and neck pain	1	Back and neck problems
Physical therapist treatment	1	Back pain	1	Lower back pain

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Table 7. Stock car driver's response to the question "Do you have any ongoing physical problems do to racing? If yes, please identify them." (N = 40).*

Main concept	No.†	Select quotes representing responses to this question
None	15	Not that I know of
Back pain	9	Back pain from stiff suspension
Neck pain	6	Whiplash, my neck hurts
Wrist/hand problems	5	Racers wrist, thumb problems
Hearing loss	2	I have some hearing loss
Shoulder pain	1	Pain in my shoulder
Triceps tendonitis	1	Triceps tendonitis from steering
Grinding teeth	1	Grind teeth while driving so teeth get wore down
Knee problems	1	ACL injury

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†The number of study participants whose answers are included in this category.

Subjects who were interested in participating were asked to respond by e-mail or telephone. At this point, a telephone interview was scheduled at a time that was convenient for the subject. The mean duration of the interviews was 43.9 ± 13.9 minutes. After the data were collected, a report of survey findings was mailed to all survey participants.

Statistical Analyses

The interview contained open-ended, numerical, and 10-point Likert's scale questions. Data from numerical and Likert's scale questions were analyzed using Pearson's correlation coefficient to examine potential relationships between a variety of variables assessed in the survey.

Table 8. Stock car driver's response to the question "What racing-related injuries are you concerned about in the future, if any?" (N = 40).*

Main concept	No.†	Select quotes representing responses to this question
Fire/burns	20	Fire being burned to death; fire, being upside down and pinned in; hot fluids
Head and neck injury	19	Neck and head injury, breaking my neck, concussion
None	7	Not really, pray a lot and trust in God's plan, can't go to the track with fear, have not ever thought about it
Hand and wrist injury	7	Broken wrists, hands getting outside of car is a wreck, thumb injuries
Death	5	Death, but I try not to think about it; death from crashing is in the back of my mind
Smoke inhalation	5	Carbon monoxide from exhaust fumes
Accidents in the pits	3	Getting hit in the pits
Injuries from rollover	3	Flipping upside down and getting hit
Hearing loss	1	Hearing loss
Heat exhaustion	1	Heat exhaustion
Back pain	1	Back pain
Injury from drive shaft	1	Injury from drive shaft coming through floor
Feet injuries	1	Feet move around the most in a wreck
Injuries from objects coming into car	1	Worried about things coming into the car

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Table 9. Stock car driver's response to the question "What can be done to prevent injuries?" (N = 40).*

Main concept	No.†	Secondary concept	No. †	Select quotes representing responses to this question
Things each driver can do	40	Racing suit and accessories	11	Nomex underwear; 2 layer or better suit; wear racing gloves, what can you do without your hands?
		Head and neck restraint	8	Use the HANS
		Keep equipment in good condition	6	Use good seat belts and mounts, check stuff regularly
		Use a good safety seat	4	Use a full containment seat, seat with head supports
		Use a fire suppression system	3	Have an on board fire extinguishing system
		Use good roll bar padding	2	NASCAR-grade roll cage padding
		Be physically fit	2	Perform weight training and cardio
		Wear eye protection	1	Wear eye protection
		Check tires	1	Keep track of your tire condition
		Use a fresh air system	1	I am thinking of using a fresh air system, worried about carbon monoxide
		Use less lightweight parts	1	Don't use drilled bolts for control arms to lighten bolts
Things tracks can do	26	Track facilities	9	Safer barriers, better retaining walls, better lighting, caution light location
		Track safety rules	5	Mandate HANSs, mandate full containment seats and arm restraints, require driver physicals, center drivers
		Track safety crew	5	Proper training for safety crew; get a safety crew, we only have two EMTs with a fire extinguisher
		Track inspection	4	Tracks enforcing safety regulations; tracks should check car safety
		Other	3	Track insurance; track should educate drivers about injuries
Things manufacturers can do	6	Make safety equipment affordable	5	Reduce price of safety equipment
		Modify head restraints	1	Create restraints that allow one to be able to turn head
Things crews can do	2	Spotters	2	Use good spotters
None	2	None	2	Things are pretty safe as they are

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Answers to open-ended questions were content analyzed according to the methods described by Patton (24) and previously used in studies assessing strength and conditioning practices of high school (7) and professional sports (8,9). The researchers generated main and secondary concept themes via inductive content analysis of the raw data. At the point of development of main and secondary concept themes, deductive analysis was used to confirm that all raw data themes were represented within these main and secondary concept themes.

Results

Results revealed significant correlation ($p \leq 0.05$) between track points standings and the length of the resistance training sessions ($R = -0.71$, $p = 0.002$) and subjects' self-assessment of their fitness ($R = -0.53$, $p = 0.045$). No significant correlations ($p > 0.05$) were found between subject track points standing and other measures of fitness, age, or experience. Results of the qualitative analysis of open-ended questions regarding the physical demands of stock car racing are shown in Tables 1–4. Tables 5–9 show the results of survey questions evaluating the injuries associated with stock car racing. Tables 10–13 show the results of survey questions demonstrating the conditioning practices and athletic experience of the subjects. Subjects reported participating in 2.94 ± 0.99 days of resistance training per week with each session having an average duration of 49.78 ± 24.56 minutes. These training sessions included 2.58 ± 0.75 days of upper-body resistance training per week and 2.19 ± 0.77 days of lower-body resistance training per week. Subjects also reported participating in 2.81 ± 1.43 days of cardiovascular training sessions per week for an average duration of 34.96 ± 15.53 minutes.

Table 10. Resistance and cardiovascular exercises performed by stock car drivers (N = 40).

Resistance training exercises	No.	Cardiovascular exercises	No.
Bench press	13	Running	14
Squat	10	Run on treadmill	9
Biceps curls	10	Bike	9
Shoulder press	8	Swim	8
Forearm exercises	8	Walk	8
Sit-ups	7	Elliptical trainer	4
Push-ups	7	Recreational sports	4
Triceps extension	7	Ski	2
Leg press	5	Martial arts	2
Chest flys	4		
Chest machine	3		
Back extension	3		
Dips	3		
Lat pull-downs	3		
Calf extension/raises	3		
Deadlift	2		

Table 11. Reasons that stock car drivers perform resistance training (N = 40).*

Main concept	No.†	Select quotes representing responses to this question
Strength for racing	20	Gotta have upper body strength for racing, reduces fatigue at the end of the race, stronger core for racing
General fitness	11	Keeps me active and in shape
Mental toughness	2	It helps to push you mentally
Accomplishment	1	Gives you a feeling of accomplishment
Increase energy	1	Gives me energy
Excitement	1	Excitement
Physical appearance	1	To look decent
Fitness for the military	1	For the guard

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Table 12. Reasons that stock car drivers perform cardiovascular training (N = 40).*

Main concept	No.†	Select quotes representing responses to this question
Conditioning for racing	18	Builds my endurance for racing, to be able to breathe under pressure during racing
General health and fitness	13	To be more fit, good health and good heart
Weight control	5	To keep my weight down
Temperature regulation for racing	4	To get used to high temps for long durations, for racing
Mental acuity for racing	4	Give me an edge mentally, so I don't feel drained and lose concentration
Improve blood pressure	1	It improves my blood pressure
Improve sleep	1	So I sleep good at night
To feel good	1	To feel good

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Table 13. Junior high, high school, and college athletic experiences of the stock car drivers (N = 40).

Junior high	No.	High school sports	No.	College	No.
Football	17	Football	16	None	35
Baseball	12	Basketball	11	Football	1
Basketball	12	Baseball	10	Basketball	1
None	6	Track	6	Baseball	1
Hockey	3	None	5	Hockey	1
Soccer	3	Soccer	3	Volleyball	1
Wrestling	3	Wrestling	3		
Track	2	Hockey	3		
Volleyball	1				
Tennis	1				

Discussion

This is the first comprehensive study of the physical demands, injuries, and conditioning practices of stock car drivers and serves as part of the need analysis for understanding this previously understudied sport. There are approximately 1,500 race tracks in the United States with larger and more populated states having as many as 79 stock car tracks (25). Thus, the number of stock car drivers is likely to be significant. These data can be used to guide the strength and conditioning services offered to this population of athletes.

The most commonly identified physical demand for stock car racing is upper-body strength, which all subjects identified as one of the top 5 physical demands associated with racing. These demands are associated with steering, steering when the power steering system fails, and steering when there is tire to tire contact with other stock cars or when the tires contact the track wall because these events can cause ballistic movement of the steering wheel. Some subjects indicate that dirt track racing, compared with asphalt, may include more steering wheel work. These findings of the need for upper-body strength are somewhat consistent with previous research, demonstrating that drivers of open wheel race cars had greater upper-body strength than controls (1). Additionally, hand and arm strength has previously been recommended in anecdotal reports for Indy Car drivers (13) and as part of the strength and conditioning program for stock car drivers (10).

This study shows that the second most common physical demand associated with stock car racing is cardiovascular endurance. Subjects in this study recognized the importance of endurance and managing heart rate during racing to prevent fatigue and the loss of focus while racing. Previous research with open wheel and formula car racing indicated fairly high $\dot{V}O_2$ demands and heart rates as high as 180 $b \cdot min^{-1}$ in open wheel formula cars (19) and nearly 150 $b \cdot min^{-1}$ during simulated race in late model asphalt cars (12). These demands were similar to those of more traditional sports such as basketball, boxing, and soccer. High heart rates during racing are likely because of significant levels of acute physical exertion as evidenced by elevated creatine kinase levels and increased liver metabolism (27).

The third most common physical demand was identified as heat tolerance, confirming that this is an issue for this population of drivers, as has been suggested (10), and previously demonstrated for drivers of formula cars (19). Increased activation of the sympathetic nervous system because of emotional stress and fluid volume shifts occurs because of in-car temperatures that are reported to be as high as 150°, potentially adding to the thermal stress (19).

Neck, core, and leg strength were also identified as common physical demands associated with stock car racing, consistent with previous reports for stock car drivers (10), and demonstrated for open wheel race car drivers (1). Practical recommendations to focus on training hand, ankle, and trunk strength have been made for open wheel and formula car endurance and road course racers because these are variables where the drivers demonstrated greater strength than controls (1). However, the lower-body demand on short track stock car racers is likely to be substantially higher than their road course counterparts because of the frequent need to break and accelerate during corner entry and exit. Additionally, lateral horizontal acceleration forces expressed as a product of gravitational forces (G) have been found to average more than 2 G in late model stock cars at competitive speeds on an asphalt track, based on recent unpublished research from the author's laboratory. These G-forces, and their effect on the core and legs, were found to be a fairly common physical demand as identified by subjects in this study, as previously suggested (10), and identified for open wheel car drivers (19). Other physical demands of stock car racing included hand/eye/foot coordination and reflexes and reaction time as speculated (10) and demonstrated with Indy Car and British sports car drivers (3,13).

In an attempt to obtain additional information about the demands of driving a stock car and to cross-check the subjects' responses to the question asking them to identify the top 5 physical demands associated with racing, drivers were asked to identify how they felt after a race. Responses to this question generally confirmed the physical demands identified by the subjects. Many subjects reported feeling "fatigue" or "extreme fatigue," consistent with previous research with race car drivers in national class cars in Greece that demonstrated intense physical exertion with heightened oxidative stress and muscle metabolism (27) and energy expenditures that have been reported to be similar to running 5–6 miles per hour (15). However, these values were attained in a nonracing high-speed driving situation (15) and are likely to be higher during competition. Subjects in the present study

also reported increased thirst and perspiration, such as "being saturated with sweat," which is consistent with previous reports of thermal stress during open wheel racing (19) that has risen to the level of heat stroke in some Grand Prix and Formula car drivers (17) and high levels of cardiorespiratory demands as found with other forms of racing (15,16). Subjects in the present study identified a variety of other physical demands that practitioners should consider when working with this population of athletes. In addition to physical demands, these subjects identified a variety of injuries associated with stock car racing.

In the present study, 43% of subjects had upper extremity injuries and 17.5% had lower extremity injuries, compared with 13% and 17.5%, respectively, in previous studies of drivers who required hospitalization for their injuries (5). In the present study, the most commonly reported problems were back injuries, although head and neck injuries were the most likely to require hospitalization. For those injuries requiring care at a hospital, 12.5% were concussions compared with previous reports of concussions ranging from 2 to 5.4% of racing injuries (5,21), potentially reflecting and increased awareness and assessment of concussion in the sports medicine profession. In the present study, 12.5% had neck injuries that required hospital care, whereas previous reports ranged from 16 to 34% of race car drivers having these injuries (5,21). Despite remaining a concern, some sources indicate that head and neck injuries may be decreasing in racing (23). These changes may be because of advances in technology and use of head and neck restraining devices, which appear to have become more popular after the death of a high profile stock car driver in 2001. Five percent of subjects in the present study had back or torso injuries that required hospital care compared with 16.7% in previous research (5). In the present study, 7.5% of the subjects had extremity injuries requiring a hospital visit and 25% had an extremity injury that required some type of medical treatment compared with as many as approximately 55% in a previous report (5,21). Of the subjects in the present study, 37.5% reported no ongoing physical problems, whereas 22.5% reported ongoing back pain and another 15% suffered from neck pain. These types of physical problems ranged from 63 to 88% for Grand Prix race car drivers (4).

Physical strength has been reported to potentially serve a role in injury prevention in automobile racing (13). Based on the results of the present study, it is plausible that some stock car racing injuries such as those associated with the back, neck, shoulder, hand, knee joint, and shoulder joint and some pulled muscles may be reduced with good strength and conditioning programs and practices.

Subjects in this study performed resistance training for an average of nearly 3 days a week with an average of approximately 2.6 days of upper-body training and 2.2 days for lower-body training. This frequency and volume seem to be within commonly recommended ranges (2). Results revealed significant correlation between track points standings (rank) and the length of the resistance training sessions and subjects' self-assessment of their fitness. Thus, conditioning for racing is related to racing success to some degree. Nonetheless, only 18 of the 40 subjects participated in resistance training. For those who participated in resistance training, exercise selection included more upper- than lower-body exercises, reflecting the subject's identification that upper-body physical demands are greatest in this sport and upper-body injuries and fatigue and are experienced by approximately 43 and 18% of the drivers, respectively. Seven of the 10 most common exercises identified by the subjects in the present study focused on the upper body. Only 4 of the 16 resistance training exercise identified by these subjects could be defined as lower-body exercises. Two exercises that were identified specifically train the core, although exercises such as the squat and dead lift also likely train the core.

Many of the subjects were athletes when they were in junior high school and high school, and a small number of these subjects were college athletes as well. Although a background in football was most common, these subjects participated in a wide range of sports, suggesting that no particular athletic background may be best suited for racing. Several of the subjects indicated that they needed to suspend their participation in traditional sports to pursue their racing careers. Because racing requires varied physical abilities such as strength, quick reactions, and muscular and cardiovascular endurance, it is likely that the physical development accrued through a variety of sports may be useful for the stock car driver.

Upper-body strength was identified as the most important physical ability for driving stock cars by 100% of the subjects in this study. This finding was confirmed in part by the subjects who also identified upper-body soreness as the most common source of muscle soreness after races. Subjects also reported upper-body fatigue after races. The upper-body demands associated with stock car racing are further illustrated in this study by the number of upper-body injuries, particularly for the hand and wrist. A number of subjects reported that these injuries were because of ballistic movements of the steering wheel when the front wheels of the stock car make contract with other cars or the wall. These subjects appear to recognize the importance of upper-body strength training as 4 of the top 5 exercises they performed were upper-body exercises such as the bench press, biceps curls, and shoulder exercises, with subjects identifying the desire to gain strength for racing as their primary motivation for performing resistance training.

Approximately 62.5% of the subjects in this study reported cardiovascular endurance as one of the top physical demands of driving a stock car. This result is consistent with the reports of many drivers who reported feeling intense or moderate fatigue and cardiorespiratory effects such as elevated heart rate and shortness of breath while racing. Over half of the subjects who perform cardiovascular conditioning sought to improve conditioning for racing and to improve

thermoregulation. In fact, heat tolerance was identified as the third most important physical demand of stock car racing. Not surprisingly, the second most common answer to the question asking subjects how they felt after racing was related to thirst and perspiration.

Training the neck and core was the fourth most important physical demand identified by 37.5% of the subjects. Neck and head soreness and head and neck injuries were each identified in the top 3 concerns for each category. However, no drivers reported performing any neck strengthening exercises. Lower-body strength was identified as the fifth most important physical demand for these subjects because of breaking and working the clutch while racing the stock car. One driver stated, "I stand on the breaks as hard as I possibly can going into every turn." There is likely to be a difference between asphalt and dirt track racing because corner entry in asphalt racing is more controlled and thus more breaking may occur upon corner entry. Other demands on the legs include managing lateral acceleration forces. Thirty percent of drivers indicated that hand eye and foot coordination was an important physical demand associated with stock car racing, whereas 25% of subjects reported that coping with high lateral acceleration forces was an important physical demand associated with racing. Finally, approximately 22% of subjects indicated that reflexes and reaction time were important physical demands, demonstrating that a variety of factors other than strength and endurance are important for racing, as previously reported (10).

Practical Applications

This is the first research article to characterize the physical demands, injuries, and fitness practices of stock car racing. Results of this article can serve as part of the needs analysis of this sport and guide strength and conditioning practitioners in their program design and work with this understudied population of athletes.

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