Open-Wheel Race Car Driving: Energy Cost for Pilots

Bruno Beaune, Sylvain Durand, and Jean-Pierre Mariot

Interactions Performance, Laboratory, Faculty of Sciences and Technology, University of Maine, Le Mans, France

Abstract

Beaune, B, Durand, S, and Mariot, J-P. Open-wheel race car driving: Energy cost for pilots. *J Strength Cond Res* 24(11): 2927–2932, 2010—The aim of this study was to evaluate the energy cost of speedway open-wheel race car driving using actimetry. Eight pilot students participated in a training session consisting of 5 successive bouts of around 30 minutes driving at steady speed on the Bugatti speedway of Le Mans (France). Energy expenditure (EE, kcal) was determined continuously by the actimetric method using the standard equation. Energy cost was estimated through physical activity ratio (PAR = EE/BMR ratio, Mets) calculation after basal metabolism rate (BMR, $kcal \cdot min^{-1}$) estimation. A 1-met PAR value was attributed to the individual BMR of each volunteer. Bout durations and EE were not significantly different between driving bouts. Mean speed was 139.94 ± 2.96 $km \cdot h^{-1}$. Physical activity ratio values ranged 4.92 ± 0.50 to 5.43 ± 0.47 Mets, corresponding to a 5.27 ± 0.47-Mets mean PAR values and a 1.21 ± 0.41 $kcal \cdot min^{-1}$ mean BMR value. These results suggest that actimetry is a simple and efficient method for EE and PAR measurements in motor sports. However, further studies are needed in the future to accurately evaluate relationships between PAR and driving intensity or between PAR and race car type.

Key Words actimeter, energy expenditure, physical activity ratio, motor sports

Introduction

During motor sports, many factors have to be taken into account to manage performance, that is, vehicle characteristics or pilot abilities. Because of important financial consequences and technical facilities, important attention has been focussed on vehicle improvement, providing numerous progresses in motor, suspensions, or pneumatics efficiency and in fuel consumption. Conversely, security rules, cockpit exiguity, and the relative discomfort of apparatuses make physiological measurements hard to perform at pilot level during driving. Thus, only results from maximal cycling tests in laboratories are routinely available. The related published studies suggest then that motor sport pilots exhibit maximal oxygen consumption ($\dot{V}O_2max$) similar to basketball or soccer players (3,10,16).

It is well established that energy expenditure (EE) is strongly related to oxygen consumption ($\dot{V}O_2$) for almost activities and sports, and that a physical activity ratio (PAR, Mets) can be determined for each activity in Humans. For example, values ranged from 1.5 to 2.5 Mets for driving various vehicles (18), but these values ranged 7.0–8.0 Mets for basketball and soccer playing (1,20). It has also been proved that EE depends on 2 main factors: exercise intensity and exercise duration (1,18,20). Regularly updated EE and PAR data are well documented but still lacking in competitive driving although they could provide essential information to coaches (trainers) and medical staff for performance management, nutritional replacement, and health preservation.

Based on these observations, we measured EE and PAR values during driving using a new technical approach: Actimetry and hypothesized that bioenergetical adaptations to open-wheel race car driving would be in the same order as those previously described in other sports such as soccer or basketball, but higher than those described for related driving activities under uncompetitive conditions.

Methods

Experimental Approach to the Problem

These past years, size reduction and reliability enhancement of sensors such as accelerometers or actimeters have allowed for new methodological approaches in EE determination in a wider range of populations or situations (7,9,11,14). Thus, we decided to measure energy expenditure in young pilot students during a speedway open-wheel race car driving training session by using an actimetric method.

Measurements were performed during a driving training session in the beginning of July 2008, corresponding to the end of the regular sport driving season, on the Bugatti Speedway of Le Mans (lap distance: 4.135 km). The training session consisted of 5 successive bouts of around 30 minutes driving at steady speed. Bouts 1 and 2 took place in the morning and were separated by a 1-hour rest and debriefing interval. Bouts 3–5 took place in the afternoon and were also

Address correspondence to Bruno Beaune, bruno.beaune@univ-lemans.fr.

24(11)/2927–2932

Journal of Strength and Conditioning Research
© 2010 National Strength and Conditioning Association

Copyright © National Strength and Conditioning Association Unauthorized reproduction of this article is prohibited.

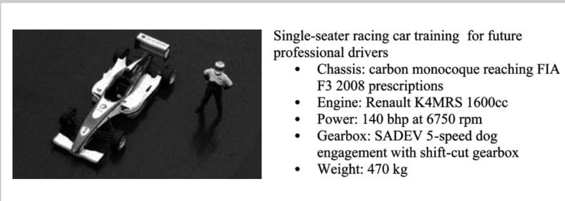

Figure 1. Single-seater racing car training for future professional drivers. Chassis: carbon monocoque as per FIA F3 2008 prescriptions; Engine: Renault K4MRS 1,600 cc; power: 140 bhp at 6,750 rpm; gearbox: SADEV 5-speed dog engagement with shift-cut gearbox; and weight: 470 kg.

separated by similar 1-hour rest and debriefing interval. Time interval between bouts 2 and 3 was 2 hours long, including rest, debriefing, and lunch.

All along the experiment, ambient temperatures moved from 10°C in the morning to 16°C in the afternoon. The vehicles were open-wheel race and training car designed as "Formula academy" able to develop a 140 bhp maximum motor power at 6,750 rpm and a 215 km·h^{-1} maximum speed (Figure 1).

Subjects

Eight pilot students of the Autosport Academy (ASACAD) of Le Mans (France) participated after getting information about the procedure and individual approval, according to the terms and procedure as per national requirements.

All pilot students were engaged in an annual driving scholar formation, consisting of participation in an internal championship including 8 races, each being preceded by a specific thematic training session 2 weeks before. All pilot students presented at least a 2-year-experience for piloting race or karting car on a speedway when recruited by the school.

Pilots wore specific protection-suit, gloves, shoes, crash helmet, and Hans's system for neck protection during driving bouts (Figure 1). Between driving bouts, pilots removed their

Table 1. Anthropometric and general characteristics of the pilots.*

Parameters	Mean ± *SD*
Age (y)	18.75 ± 3.41
Height (cm)	178.38 ± 7.78
Weight (kg)	64.13 ± 8.22
BMI (kg·m^{-2})	20.12 ± 1.83
BMR (kcal·min^{-1})	1.21 ± 0.09

*All results are expressed as mean ± *SD*; BMI = body mass index = $weight_{(kg)}/height_{(cm)}^2$; BMR = basal metabolic rate (4).

Table 2. Duration, speeds, and energetic values during driving bouts.*

Driving bout	Bout 1	Bout 2	Bout 3	Bout 4	Bout 5	Mean	Total
Bout duration (min)	28.22 ± 3.01	28.66 ± 5.94	26.67 ± 4.93	28.58 ± 4.63	24.94 ± 6.50	27.81 ± 1.50	121.72 ± 16.73
Mean speed (km·h^{-1})	137.90 ± 2.14	138.07 ± 1.71	135.03 ± 3.60†	138.21 ± 1.69†	127.26 ± 10.90	134.94 ± 2.96	
Peak speed (km·h^{-1})	141.02 ± 2.49	141.70 ± 1.51	141.53 ± 1.03	141.50 ± 1.51	142.09 ± 1.68	141.61 ± 1.56	
EE (kcal)	191.25 ± 62.45	187.50 ± 45.34	158.50 ± 33.18	182.00 ± 39.14	179.00 ± 31.00	177.73 ± 21.86	780.25 ± 149.07
PAR (Mets)	5.43 ± 0.45	5.42 ± 0.71	4.92 ± 0.50†‡	5.24 ± 0.46	5.42 ± 0.50	5.27 ± 0.47	

*All results are expressed as mean ± *SD*; EE = total energy expenditure; PAR = physical activity ratio. PAR value (Mets) was calculated using EE/BMR ratio, after BMR (basal metabolic rate) determination using the standard equation from (4).
†$p < 0.05$ between bout considered and the previous one.
‡$p < 0.05$ between bouts 3 and 5.

Copyright © National Strength and Conditioning Association Unauthorized reproduction of this article is prohibited.

TABLE 3. Correlation table.*

r/(p)	EE × duration	EE × speed	PAR × duration	PAR × speed
Bout 1	0.966 (†)	0.994 (†)	0.534 (NS)	0.749 (NS)
Bout 2	0.816 (†)	−0.644 (NS)	−0.099 (NS)	0.371 (NS)
Bout 3	0.875 (‡)	−0.339 (NS)	−0.177 (NS)	−0.069 (NS)
Bout 4	0.796 (†)	−0.489 (NS)	−0.371 (NS)	0.091 (NS)
Bout 5	0.845 (†)	0.026 (NS)	0.779 (†)	0.269 (NS)

*EE = energy expenditure; PAR = physical activity ratio. PAR value (Mets) was calculated using EE/BMR ratio, after BMR (basal metabolic rate) determination using the standard equation from (4).
†$p < 0.05$.
‡$p > 0.01$.

gloves, crash helmets, and Hans's system. They opened their suit and turned it down at hip level.

Procedures

For each subject, lap time during each driving bout was measured using an infrared timing device, and data were used for calculation of the mean driving bout speed and determination of the driving bout duration.

Energy expenditure was evaluated continuously by actimetric method using Armband Sensewear Pro™ actimeter (Bodymedia Inc., Pittsburg, PA, USA) located at the third upper right arm part. The sensor was installed half an hour after the last driving bout ended and retired half an hour after the last driving bout. Basal metabolism rate (BMR, $kcal \cdot min^{-1}$) was estimated using the standard equation (4). Energy expenditure was estimated through physical activity ratio (PAR = EE/BMR ratio, Mets) and after attributing a 1-met PAR value to the individual BMR of each volunteer.

Statistical Analyses

Because of the small number of subjects, we decided to present values as mean ± *SD* rather than as *SEM*. All tests and analysis were conducted using STATVIEW 5.1 software (Statistical Analysis System, Cary, NC, USA). A nonparametric test procedure was applied for statistical analysis of data differences between pilots (Mann–Whitney's test) and between driving bouts for all pilots (Wilcoxon's test). For each driving bout, a correlation analysis was made to evaluate relationship levels either between age, height, body weight (BW), and EE or between age, height, BW, and PAR variations. Statistical significance was estimated using the "r en z" Fisher's post hoc test. Statistical significance was accepted when $p \leq 0.05$.

RESULTS

All the pilots studied presented similar anthropometric characteristics (Table 1). Similarly, nonsignificant differences were found in bout duration, speed, and energetic values between pilots, whatever the driving bout considered.

Comparison between Driving Bouts

No significant differences were found in peak speed (mean value = 141.61 ± 1.56 $km \cdot h^{-1}$) and EE (mean value = 117.73 ± 21.86 kcal) between the driving bouts considered (Table 2).

Mean speed during driving bouts was 134.94 $km \cdot h^{-1}$. There were significant differences in mean speed between bouts 4 and 1 (138.21 ± 1.69 vs. 137.90 ± 2.14 $km \cdot h^{-1}$, respectively; $p < 0.05$), and between bouts 4 and 3 (138.21 ± 1.69 vs. 135.03 ± 3.60 $km \cdot h^{-1}$; $p < 0.05$) (Table 2). Physical activity ratio values were significantly different between bouts 2 and 3 (5.42 ± 0.71 vs. 4.92 ± 0.50 Mets, respectively; $p < 0.05$) and between bouts 3 and 5 (4.92 ± 0.50 vs. 5.42 ± 0.50 Mets, respectively; $p < 0.05$) only (Table 2). The mean PAR value for the 5 driving bouts was 5.27 ± 0.47 Mets.

Analysis of Correlation

Energy expenditure and PAR values were not significantly correlated to age, height, and BW whatever the driving bout considered. A significant correlation was obtained between bout duration and EE for all driving bouts, and between mean bout speed and EE during the first driving bout ($p < 0.05$; Table 3). Correlations were significant between PAR values and bout duration only during bout 5 ($p < 0.05$; Table 3).

DISCUSSION

Our study is the first to provide reliable measurements of mean PAR value (5.27 Mets) during driving a race and training car (Formula Academy) slightly lower than those previously observed in other sports such as basketball or soccer (1,20). They also suggest that actimetry could provide an effective method for EE measurement during race car driving under close conditions. At least, they indicate that EE during driving could be influenced by several factors such as driving intensity (mean speed) or environmental conditions and give evidences for further investigations.

The energy cost of physical activity has been extensively studied for a long time, and it is now well established that all sports can be classified by comparing their maximal aerobic requirement (1,2). In specialized laboratories, reliable $\dot{V}O_2max$ values are obtained routinely using standardized incremental tests and experimental conditions, including gas exchange measurements. Thus, Schwaberger (16) reported first a mean $\dot{V}O_2max$ value of 3.09 ± 0.31 $L \cdot min^{-1}$ (range: 2.57–3.59) in 20 professional car race drivers when performing standardized incremental test on a cycloergometer. $\dot{V}O_2max$ value was 3.50 ± 0.54 $L \cdot min^{-1}$, ranging from 3.00 to

Copyright © National Strength and Conditioning Association Unauthorized reproduction of this article is prohibited.

4.60 L·min^{-1}, in elite race car pilots (6). Based on these observations, these authors and others concluded that $\dot{V}O_2$max values in car race pilots were similar to $\dot{V}O_2$max values in basketball, soccer, or football players (3,6,10,16). However, these values reflect only maximal aerobic performance of pilots not EE during driving.

In various physical activities and sports such as running or cycling, direct evaluation (time, distance, speed, etc.) and the use of portable analyzers (heart rate recorders, $\dot{V}O_2$ analysers, etc.) allow for routine measurements of individual performance and EE evaluations in the usual conditions of exercise. However, it is well established that numerous factors such as ambient temperature or hygrometry can affect sensor sensitivity and individual efficiency. For these reasons, results from field measurements are considered less reliable than those from laboratory tests.

In motor sports, many other factors make EE measurements more complicated and rare. Indeed, pilots are closely strapped and installed in their personal seats to protect them during an eventual crash inducing movement limitations. The cockpit space is limited and apparatus installation is restricted to prevent indirect injuries in the case of shock. Cables from the sensors can be responsive for some inconveniences during driving. At last, security rules make compel the pilot to wear a crash helmet during both car racing and training, making direct gas exchange measurements impossible. For these reasons, to the best of our knowledge, values obtained previously (6) via the use of a portable metabolic analyzer in 7 professional open-wheel race car drivers are unique reference data for oxygen consumption ($\dot{V}O_2$) during roadway (2.76 ± 0.71 L·min^{-1}; 38.5 ± 5.5 ml·min^{-1}·kg^{-1}) and speedway (1.56 ± 0.46 L·min^{-1}; 21.9 ± 6.3 ml·min^{-1}·kg^{-1}) driving at competitive speeds. These authors also indicated that race car driving was of medium aerobic requirement corresponding to 79 and 45%$\dot{V}O_2$max, respectively. Unfortunately, direct $\dot{V}O_2$ measurements during driving are now forbidden in almost all countries, making it impossible to do a direct comparison with these findings. Thus, alternative methods have been developed for EE measurements.

Because of cockpit exiguity, work load during driving mainly consists of isometric contractions of arm muscles during curves and leg muscles to brake or accelerate. In 2005, Blackman et al. compared anaerobic potential and neuromuscular performance in 9 international-level speedway pilots, in 9 international-level rally pilots, and in 10 nonpilot active students of the same age. They did not observe any significant differences in maximal jump height and leg power between groups using maximal jump tests. Thus, they concluded that pilots and nonpilots exhibited similar maximal anaerobic abilities. Pilots and nonpilots also exhibited similar maximal isometric forces and power at leg (plantar), shoulder, and neck levels, suggesting that driving ability and corresponding energy requirements could be investigated by measuring force intensities developed by the pilot during driving. Some authors have proposed the use of accelerometers for human PAR determination, and this method has been widely investigated in various sports or free-living activities (8,13,15). Accelerometric measurements are extensively realized by motor sport professionals to manage chassis efficiency and car road holding. Conversely, in the literature, we found no studies involving an accelerometric method to evaluate EE in pilots during driving. This is likely because the ergonomics of the open-wheel car and the fact that the pilot is closely strapped to his seat limit his movements. By consequence, accelerations at the pilot level are proportional to those at the car level. It can then be postulated that accelerometers provide only indirect and incomplete measurements of pilot EE. Armband Sensewear Pro™ actimeter (Bodymedia, USA) has been previously validated for free-living conditions, at rest and exercise (11), during treadmill exercise (9), and in diabetic individuals (12). It incorporates a 2-axis accelerometer recorder to evaluate EE. These data are completed by synchronous recordings of step counting, skin and ambient temperatures, skin impedance and hygrometry. By taking into account these 5 parameters, standardized equations included in the specific Sensewear Professional® software allow for minimizing the influence of vehicle motion on EE calculations and offer a wide range of adapted situations for physical activity measurements. This is the reason why, in the absence of an alternate reliable and validated method dedicated to car racing, we choose to use actimeters for EE and PAR evaluation.

Mean speed was 139.94 ± 2.96 km·h^{-1}, and PAR values ranged 4.92 ± 0.50 to 5.43 ± 0.47 Mets, corresponding to a 5.27 ± 0.47 Mets mean PAR value and a 1.21 ± 0.41 kcal·min^{-1} mean BMR value. As observed before with $\dot{V}O_2$max values, PAR values are similar to those observed during basketball, soccer, or football (1). Moreover, when a 21-kJ value was taken into account for oxygen equivalent for energy, $\dot{V}O_2$ calculations indicated that our findings are lower but of the same order as those provided previously (6) (1.31 vs. 1.56 L·min^{-1}). All these results suggest that actimetry is not affected by accelerations at the car level and provides an accurate and alternative method for EE and PAR measurement during open-wheel car racing. However, our measurements were performed during a training session of 5 30-minutes driving at steady speed, and further studies are needed to evaluate the consequences of long-time driving and/or variations in speed driving on energy expenditure and PAR during car racing.

Moreover, as shown, no significant differences in EE or bout duration values were found between the 5 successive driving bouts, whereas a significant correlation was found between these 2 parameters. These findings are in accordance with the obligation made to the pilots to maintain a near of 140-km·h^{-1} steady speed during 5 30-minute-long driving bouts during the training session. They are also in accordance with the evidence of similar work load and force expression turn after turn during speedway driving. However, to maintain a steady speed during speedway driving is hard

Copyright © National Strength and Conditioning Association Unauthorized reproduction of this article is prohibited.

to perform by the pilots and may suffer from numerous individual events. For example, road off or mechanical breakdown induces a reduction in bout duration that can be easily identified and corrected. But, when a car skids or spins right around, a decrease in mean speed follows, which cannot be spotted by the sensors. This last phenomenon probably explains PAR differences between driving bout 3 and bouts 2 and 5 that correspond to the shortest and the longest bout durations, respectively. However, anthropometric data, bout speeds, bout durations, and PAR values were homogenous between pilots at all driving bouts indicating that such events had minor effects on PAR determination during our measurements.

Many factors can induce PAR variations during driving or other motorized activities. In a recent review of ethnical and country variations in PAR, values reported were in the range 1.92–2.59 Mets when driving a tractor, 1.64–2.87 Mets when driving a military truck and were 2.35 Mets when driving a Philippine Jeepney (18). For comparison, PAR values ranged 1.47–2.49 Mets when flying a helicopter and the value was 2.3 Mets when driving a military tank (17). In motor sports, differences in heart rate (HR) have been previously observed when comparing the physiological consequences at the heart level of driving a speedway race car, a rally car, or during motocross riding. The higher the speed, the higher is the HR(5,10,19). Similarly, during a speedway car race, when speeds reach 325–340 $km \cdot h^{-1}$ HR neighbored maximal values (6). Indeed, a higher speed induces higher braking deceleration and acceleration while maneuvering curves. To support this physical phenomenon and maintain the car on the speedway, the pilot needs to apply higher isometric forces on the steering wheel, to stimulate HR and breathing, leading to an increase in energy cost (5,19). When compared with previous work (6), all these results suggest that the mean PAR values of 5.27 ± 0.47 Mets we measured could be attributed mainly to high differences in driving speed (intensity).

Increasing speed will also induce need for higher attention, and elicit an activation of the (nor) epinephrine axis (16,19). Because our measurements were made during a training session but not during competition, the role of psycho-emotional factors in increasing energy cost cannot be proved. Another hypothesis is that pilots are exposed during driving to hot microenvironments generated by mechanical (motor), physiological (muscle activity), and ambient environment. To prevent fire damage, pilots wear special clothes that provide a thermal barrier and limits heat dissipation. During a race, a sweat blockade can occur resulting in personal discomfort and increase in energy cost (up to 11–17 Mets) (5,19). During our measurements, external temperature was moderate ranging 10–16°C, and driving bout durations were short, neighboring 30 minutes. Moreover, between driving bouts, pilots removed their gloves, crash helmet, and Hans's system. To prevent heat accumulation at upper body levels and to provide similar body thermal conditions at the beginning of each driving bouts, we asked them to open and turn down their suits at hip level. This suggests that thermal factors might represent a minor influence on PAR values during our experiments.

At least, all the mentioned factors are known to favor fatigue development at the mental level too. By using a psychomotor test, it was shown that fatigue development induced by a 15-minute pedaling effort induced a decrease in attention and reduced reflexes during a 3 × 12-minute-long simulated car race (19). Moreover, when reviewing multiple events that occurred during F1 speedway competitions in the past years, a direct relationship has been clearly established between fatigue development and increase in behavioral mistakes, responsible for road off or crashes (5). During F1 or rally car race, peak speeds are high (over 300 and 180 $km \cdot h^{-1}$, respectively) and competition consists of performing a limited distance (turn number or "specials") with minimal duration. During endurance car racing, time duration is limited, and competitors have to perform the longest distance they can. To prevent risk damage and progressive decrease in performance because of cumulative fatigue, the pilot has to adjust his driving mainly by reducing mean speed. During their training session, the pilot students performed 5 successive 30-minute driving bouts. Although PAR values were similar during bouts 2 and 5 (5.42 ± 0.71 and 5.42 ± 0.50 Mets, respectively), mean speed was 11 $km \cdot h^{-1}$ higher in bout 2 than in bout 5. Even if the difference was not significant, it can be hypothesized that the lower mean speed measured in bout 5 compared with others was the consequence of a fatigue accumulation resulting in an increase in PAR values. However, this hypothesis has to be corroborated by further investigations.

In conclusion, our results suggest that actimetry is a simple and efficient method to measure EE and PAR during sport driving activity. For a mean speed close to 140 $km \cdot h^{-1}$, a PAR value of 5.27 Mets has been estimated for speedway race car driving. Because of the specific conditions of measurements (pilot student, training, steady speed, 30-minute-long driving bouts), complementary studies are needed in the future to emphasize the influence of driving intensity and duration, and the role of psychomotor factors on the energy cost of competitive pilots.

Practical Applications

As indicated before, EE measurements by actimetry during training could be of great interest to estimate EE during race in motors sports, providing to coaches arguments for the elaboration of specific nutritional strategy and training program to prevent fatigue development during competitions. For example, at the pilot level, endurance car races are characterized by alternation of driving sessions and resting periods. At the team level, cars are successively driven by 3 or 4 pilots, and team performance depends on addition of individual pilot performances. If considering that an abnormally increased PAR level measured for a pilot during

Copyright © National Strength and Conditioning Association Unauthorized reproduction of this article is prohibited.

a driving phase would reflect fatigue process development, the staff could have to modify pilot behavior, and impose either shorter driving bouts or longer resting periods on a pilot. Thus, in accordance with competition rules, adaptations on pilots' alternation management could be proposed to enhance (or preserve) team performance.

Data also suggest that a defined energy cost value could be related to an optimal driving duration or an optimal speed driving. Because actimetry is a simple method for measuring EE and because actimeters are easy to use, these sensors could be applied to promote road security advising programs and accident prevention during long-distance travel. For example, knowledge on EE during driving allows for determining the best rest period frequency or food energy replacement needed. In professionals (commercial, bus, or truck driver), it could also give precise arguments to (re)define the daily maximal driving duration authorized according to vehicle type or power.

Acknowlegments

The authors thank the pilots and the staff of Autosport Academy (Le Mans, France) for their involvement all along the measurements. This work was part of a specific program "Optimisation de la performance et interactions Homme-Machine en Automobile et Aviron–OPERF2A," supported by the "Pays de la Loire" Region (France).

References

1. Ainsworth, BE, Haskell, WL, Whitt, MC, Irwin, ML, Swartz, AM, Strath, SJ, O'Brien, WL, Bassett, DR, Schmitz, KH, Emplaincourt, PO, Jacobs, DR, and Leon, AS. Compendium of physical activities: An update of activity codes and MET intensities. *Med Sci Sports Exerc* 32: S498–S516, 2000.
2. Astrand, PO, Rodahl, K, Dahl, HA, and Stromme, SB, Textbook of work physiology, 4th ed., Champain, IL: Human Kinetics, 2003.
3. Backman, J, Häkkinen, K, Ylinen, J, Häkkinen, A, and Kyröläinen, H. Neuromuscular performance characteristics of open-wheel and rally drivers. *J Strength Cond Res* 19: 777–784, 2005.
4. Black, AE, Coward, WA, Cole, TJ, and Prentice, AM. Human energy expenditure in affluent societies: An analysis of 574 doubly-labeled water measurements. *Eur J Clin Nutr* 50: 72–96, 1996.
5. Carneiro-Rodrigues, LO and De Castro Magalhaés, F. Car racing: In the heat of competition. *Rev Bras Med Esporte* 10: 216–219, 2004.
6. Jacobs, PL, Olvey, SE, Johnson, BM, and Cohn, KA. Physiological response to high-speed, open-wheel racecar driving. *Med Sci Sports Exerc* 34: 2085–2090, 2002.
7. Jakicik, JM, Marcus, M, Gallagher, KI, Randall, C, Thomas, E, Goss, FL, and Robertson, RJ. Evaluation of the Sense Wear Pro Armband™ to assess energy expenditure during exercise. *Med Sci Sports Exerc* 36: 897–904, 2004.
8. Jakicik, JM, Winters, C, Lagally, K, Ho, J, Robertson, RJ, and Wing, RR. The accuracy of the triTrac-R3D accelerometer to estimate energy expenditure. *Med Sci Sports Exerc* 31: 747–754, 1999.
9. King, GA, Torres, N, Potter, C, Brooks, TJ, and Coleman, KJ. Comparison of activity monitors to estimate energy cost of treadmill exercise. *Med Sci Sports Exerc* 36: 1244–1251, 2004.
10. Konttinen, T, Kyröläinen, H, and Häkkinen, K. Cardiorespiratory and neuromuscular response to motocross riding. *J Strength Cond Res* 22: 202–209, 2008.
11. Malavolti, M, Pietrobelli, A, Dugoni, M, Poli, M, de Cristofaro, P, and Battistini, NC. A new device for measuring daily total energy expenditure (TEE) in free living individuals. *Int J Body Comp Res* 3: 63–65, 2005.
12. Mignaud, D, St. Onge, M, Karelis, AD, Allison, DB, and Labasa-Lhoret, R. Evaluation of the portable healthwear armband–a device to measure total daily energy expenditure in free-living type 2 diabetics individuals. *Diab Care* 28: 225–227, 2005.
13. Montoye, HJ, Washburn, R, Servais, S, Ertl, A, Webster, JG, and Nagle, FJ. Estimation of energy expenditure by a portable accelerometer. *Med Sci Sports Exerc* 15: 403–407, 1983.
14. Parker, G, Gladstone, G, and Hadzi-Pavlovic, D. Measuring psychomotor agitation by use of an actimeter. *J Affect Dis* 72: 91–94, 2002.
15. Plasqui, G, Josen, AM, Kester, AD, and Norman, RW. Transfers of mechanical energy within the total body and mechanical efficiency during treadmill walking. *Ergonomics* 23: 147–156, 2005.
16. Schwaberger, G. Heart rate metabolic and hormonal responses to maximal psycho-emotional and physical stress in motor car racing drivers. *Int Arch Occup Environ Health* 59: 579–604, 1987.
17. Thornton, R, Brown, GA, and Higenbottam, C. The energy expenditure of helicopter pilots. *Aviat Space Environ Med* 55: 746–750, 1984.
18. Vaz, M, Karaolis, N, Draper, A, and Shetty, P. A compilation of energy costs of physical activities. *Publ Health Nutr* 8: 1153–1183, 2005.
19. Walker, SM, Dawson, B, and Ackland, TR. Performance enhancement in rally car drivers via heat acclimatation and race simulation. *Comp Biochem Physiol Part A* 128: 701–707, 2001.
20. Wilmore, JH and Costill, DL. *Physiology of Sport and Exercise* (2nd ed.). translated by A. and P. Delamarche: De Boeck Université, Paris, 2002.

Copyright © National Strength and Conditioning Association Unauthorized reproduction of this article is prohibited.