Cardiac chronotropic adaptation to open-wheel racecar driving in young pilots

Bruno Beaune and Sylvain Durand

Laboratory "Motricité, Interactions, Performance" (EA4334), Faculty of Sciences and Technology, University of Le Mans, France.

Abstract

Objectives: we aimed to evaluate heart rate (HR) response in pilots to repeated bouts of race car driving.
Design and methods: Eight young male student pilots (18.75 ± 3.41 years) participated to a training session consisting in 5 successive bouts (27.81 ± 1.50 min) of driving a ''Formula academy'' open-wheel race car on the "Bugatti" Speedway of Le Mans (France). Mean and peak speeds were calculated after lap duration measurement using a telemetric infrared timing device. HR was recorded continuously on 5-second intervals using a portable cardiometric device.
Results: when driving at a mean 134.94 ± 2.96 km/h speed, mean HR was 132.71 ± 10.71 bpm corresponding in 67.88 ± 5.37 %HR_{max} intensity. No significant differences were found between the different driving bouts whatever the parameters considered.
Conclusions: these results showed good repeatability of the measurements and they suggested that HR monitoring is a valid method to evaluate racecar pilot adaptation to driving. Moreover, the lack of relationships between duration variation, mean or peak speed and HR all along the experiment confirms the major role of muscle isometric loads on energy expenditure and therefore on HR when driving a "Formula academy" open-wheel racecar.

Key words: heart rate, motorsports, exercise

1. Introduction

In motor sports, vehicle characteristics (motor, suspensions…), pneumatics efficiency, fuel consumption have been largely taken into account to manage performance and safety. But, safety rules, cockpit exiguity, and/or the relative discomfort of apparatuses have made physiological measurements hard to perform. Consequently, little is known about pilot physiological adaptations to driving. For these reasons, previous studies mainly focused on laboratory testing or driving simulation. Results from maximal cycling tests indicated that motorsport pilots exhibit maximal oxygen consumption ($\dot{V}O_2max$) and maximal power similar to basketball or soccer players (Backman *et al*., 2005; Konttinen *et al*., 2008; Schwaberger, 1987). However, using an accelerometric method, we recently found that, in young racecar pilots, when driving at speed values neighboring 130 km/h on speedway, physical activity ratio ranged 4.92-5.43 Mets, corresponding to mean energy expenditure of 177.73 ± 21.86 kcal, and was slightly lower than in the aforementioned kinds of athletes (Beaune *et al*., 2010).

The use of heart rate (HR) in exercise prescription or management is based on the existence of a linear relationship between HR and $\dot{V}O_2$ or HR and effort intensity in healthy adults (Astrand and Rodahl, 1973; for recent review also see Da Cunha *et al*., 2010). As frequently described, low HR is associated with rest or a relaxed state while HR acceleration occurs in response to exercise, emotional stress, noisy environment, sexual arousal and mental effort. Watkins (2006) reported, in one pilot, HR reaching 200 bpm, during Monaco Formula 1 Grand Prix and 185 bpm during "24h du Mans" competition .

Based on these observations, we proposed that HR monitoring could be a valid indication of physiological work efforts when driving open-wheel race car during training and/or competition and aimed to evaluate HR response to repeated bouts of driving in young pilots.

2. Methods

2.1. 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 in accordance with 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. Between driving bouts, they removed their gloves, crash helmets, and Hans's system, opened their suit and turned it down at hip level to limit heat accumulation.

2.2. General protocol

Measurements were performed during a driving training session in the beginning of July 2008 on the "Bugatti" Speedway of Le Mans (lap distance: 4.135 km). All details concerning vehicle, pilots and equipments can be found in Beaune *et al*. (2010). The training session consisted of 5 successive 30 minutes bouts of driving a ''Formula academy'' open-wheel race car (developing a 140 bhp maximum motor power at 6.750 rpm and a 215 km/h maximum speed 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 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.

2.3. Procedure

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.

Heart rate (HR) was recorded continuously on 5s intervals using Polar S625 system (Polar Electro, Kempele, Finland) all along the training session (from 9h am to 5h pm). After recording data were transferred to computer via Polar Infrared device and analyzed using the Polar Precison Performance^{TM} 5.20 software. Resting period and driving bouts were characterized after data transfer, identification of the different phases (pre-driving and rest, driving, inter driving) and extraction on Microsoft Excel Software (Figure 1).

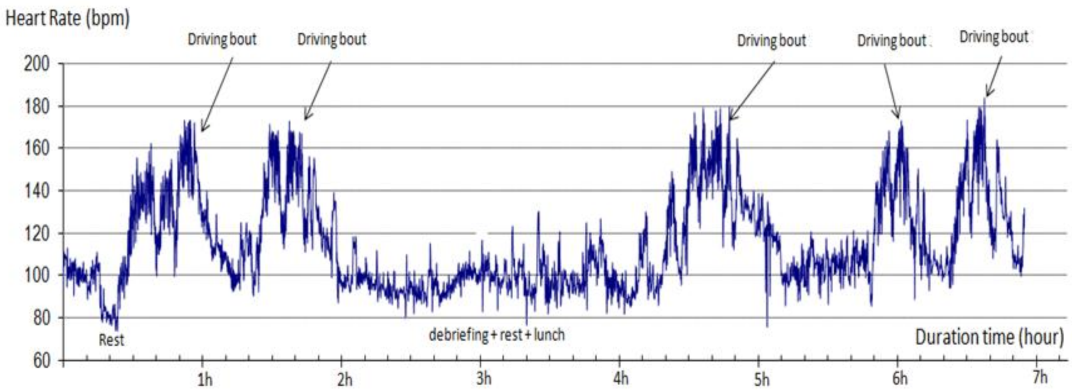

Figure 1: Example of heart rate recorded in a young pilot during open-wheel race car driving training (Data were recorded continuously every 5 seconds using a portable HR monitoring device).

Resting HR (HRr) was measured at the beginning of the recording period (when pilots were waiting for speedway ingoing) and before each driving bouts. Subjects were quietly seated in the racecar for 15 min and HRr correspond to the lowest mean value observed during 1 min.

Mean HR values were calculated by meaning steady state values corresponding to each driving bout. Maximal HR (HR_{max}) was determinated using the formula developed by Tanaka *et al* (2001) and mean driving bout intensity was expressed as HR_{max} percent ($\%HR_{max}$).

2.4. Statistical analysis

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, 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, Pearson’s correlation analysis was made to evaluate relationship levels either between duration, mean speed, peak speed, (duration X mean speed) and mean HR. Statistical significance was estimated using the ‘‘r en z’’ Fisher’s post hoc test. Statistical significance was set at $P < 0.05$.

3. Results

Pilots’ anthropometrics and general characteristics are reported in Table 1. No significant differences (NS) were found in duration, speed and HR values between pilots. As shown in Table 2, total driving duration was 121.72 ± 16.73 minutes, divided in five bout of similar mean duration (27.81 ± 1.50 minutes; NS). No significant differences between bouts were found in mean speed (134.94 ± 2.96 km/h) and peak speed (141.61 ± 1.56 km/h).

Table 1. Anthropometric and general characteristics of the subjects (n=8).

Age (y)	18.75 ± 3.41
Height (cm)	178.38 ± 7.78
Weight (kg)	64.13 ± 8.22
BMI (kg/m²)	20.12 ± 1.83
HRr (bpm)	65.00 ± 6.28
HR_{max} (bpm)	194.88 ± 2.39

All results are expressed as mean ± SD; BMI = body mass index = weight (kg)/height²(cm²); HRr = resting heart rate (beat per minute; bpm); HR_{max} = maximal heart rate – calculated according to Tanaka et al. (2001) = 208 – (0.7*Age_y).

Table 2. Duration, speed and heart rate 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	27.18±5.94	28.82±4.93	29.66±4.63	22.49±6.50	27.81±1.50	121.72±16.73
Mean speed (km/h)	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)	141.02±2.49	141.70±1.51	141.53±1.03	141.50±1.51	142.09±1.68	141.61±1.56	-----
HR_n (bpm)	143.06±4.97	130.12±11.70	129.12±19.62	134.30±12.05	134.42±5.27	132.71±10.71	108.44±13.17
Intensity (%HR_{max})	73.29±2.10	66.65±5.82	66.03±10.02	68.70±6.10	68.75±2.50	67.88±5.37	55.47±6.80

* $P < 0.05$ between bout considered and the previous one.
All results are expressed as mean ± SD; HRn = mean heart rate (beat per minute or bpm); HR_{max} = maximal heart rate.

During the five driving bouts, mean HR ranged between 143.06 ± 4.97 bpm (73.29 ± 2.10 %HR_{max}) in bout 1 and 129.12 ± 19.62 bpm (66.03 ± 10.02 %HR_{max}) in bout 3. No significant differences in mean HR or intensity were observed between bouts (NS). Analysis of correlation did not pointed out any significant relationship between bout duration and mean HR, mean speed and mean HR, peak speed and mean HR, nor between duration X mean speed and mean HR, as well when HR is expressed in absolute or in relative (intensity) values (NS).

4. Discussion

Our results give reliable accurate measurement of HR adaptations of driving open-wheel race car on speedway. They indicate that driving a Formula Academy racecar at 135 km/h during over 30 minutes can induce a mean HR elevation up to 143 bpm. Under such conditions, the good repeatability of our measurements during the 5 driving bouts suggests that HR monitoring could be a simple and reliable method to evaluate pilot adaptation to driving training.

Controversy exists in the literature about HR response to racecar driving. On one hand, our results are consistent with values from Jacobs *et al*. (2002) who reported HR values of 142 bpm when driving an open-wheel racecar at competitive velocity on speedway (225-305 km/h). Our HR measurements are also consistent with the moderate energy expenditure level observed in similar young student pilots (Beaune *et al*. 2010). Indeed, when driving an open-wheel racecar, cockpit space is limited. Pilots are closely strapped and installed in their personal seats to protect them during an eventual crash. These result in restricted movements. For these reasons, it is commonly considered that although fine motor coordination is of importance, physical efforts required to driver racecar are reduced and mainly consist in low energy cost isometric contractions of arm muscles during curves and leg muscles when braking or accelerating. At neck level, to counteract vibrations in the cockpit and helmet weight neck muscles have to work to maintain posture and inhibit G forces action. (Schwaberger, 1987; Backman *et al*., 2005; Watkins, 2006). This probably also explains why relative HR data appears lower in pilots (over 68%HR_{max}) than in basketball or soccer athletes (90-95 %HR_{max} and 80-85 %HR_{max}, respectively) (Ben Abdelkrim *et al*., 2010; Castagna *et al*., 2010), while they exhibit similar energy expenditure (Beaune *et al*., 2010).

Levine (2000) defined the concept of NEAT (*Non Exercise Activity Thermogenesis*) as "activities of daily living other than exercise (sport and fitness-related activities) and include sitting, standing, walking and fidgeting". According to this definition, it can be assumed that NEAT are implicated in postural control through muscle isometric contraction loads and that they induce an increase in energy expenditure without displacement production. Increasing speed induces higher braking deceleration and acceleration while maneuvering curves. To support this physical phenomenon and to maintain the car on the speedway, the pilot needs to apply higher isometric forces on the steering wheel, to stimulate HR and breath rate, resulting in an increase in energy cost (Carneiro Rodrigues and de Castro Magalhaes, 2004; Walker *et al*., 2001). According to all these findings, the HR increase was attributed to an increase in physical demand during high speed driving. The higher the speed, the higher the HR is.

On the other hand, high HR levels were reported in most of the studies related to physiological responses during motocross riding (Konttinen *et al*., 2008) and/or in motorsports in general (Schwaberger, 1987). In our experiments, HR values appear lower than those from Watkins (2006) who exhibited HR values reaching maximal values (close to 200 bpm) during Monaco formula one Grand Prix and 180 bpm during 24 hours racecar at Le Mans. For others authors, a step HR increase occurred at the beginning of a Formula 1 race or of a rally race, up to 170-200 bpm or even more.

These high values maintained all along the race with small fluctuations and were followed by a rapid drop just after the race (Taggart and Gibbons, 1967; Simonson *et al*., 1968; Schwaberger, 1987). Differences in HR response 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 suggesting that HR was closely related to high driving speed velocity and type of racing track (Carneiro Rodrigues and de Castro Magalhaes, 2004; Konttinen *et al*., 2008).

The influence of speed velocity driving on HR variation is not clearly established yet. As reported above, Jacobs *et al*. (2002) observed moderate increase in $\dot{V}O2$ responses as the pace of driving increased from 95 to 160 km/h on the road course and from 225 to 305 km/h on the speedway course, while HR reached 152 bpm and 142 bpm, respectively. When driving pace surpassed approximatively 300-320 km//h, a dramatic $\dot{V}O2$ elevation occurs on each racing course associated with maximal HR values. This suggest that HR adaptation to speed driving is biphasic, being progressive but relatively moderate when speed values remain under threshold value but fast when speed surpassed such a threshold value. When driving a CART-series open-wheel racecar, they estimated that threshold value corresponded to a relative 90-92% peak sustained velocity (325-340 km/h). This hypothesis is supported by previous findings from Hoffman and Reygers (1960) who did not observed significant effect of mere speed on HR during rally road driving as long as speed velocity was less than 145 km/h or 90 miles/h.

In our experiment, mean speed was relatively stable (around 135 km/h) all along the 5 driving bouts and no significant differences were observed between driving bouts neither for mean speed nor peak speed (Table 2). Moreover, the highest mean HR was recorded during driving bout 1 (143.06 ± 4.97 km/h), the lowest speed during driving bout 3 (129.12 ± 19.62 km/h) while mean HR was 137.90 ± 2.14 bpm and 135.03 ± 3.60 bpm respectively (Tableau 2). During driving bout 4, mean speed was 134.42 ± 5.27 km/h while mean HR was 127.26 ± 10.90 bpm. When compared to previous studies cited, the mean speed measured was low. This probably supports the hypothesis that as long as speed velocity does not reach threshold value it significantly affects isometric loads at arm, leg and neck levels resulting in corresponding HR values relatively stable. This may also explain the lack of correlation between duration and HR, mean speed and HR, (duration x mean speed) and HR we observed (Table 3). This hypothesis is corroborated by Watkins (2006) when comparing HR between successive measurements during repeated laps of Monaco or Le Mans circuit. Indeed, when pilot was in “Hunaudières straight”, the fastest part of Le Mans circuit, speed reached at least 340-350 km/h but with HR at its lowest level (135-155 bpm). Conversely, HR reached highest values (155-180 bpm) when the pilot was between the “Arnage curve” and the “Ford curve”, corresponding to the lowest part of the circuit (110-130 km/h).

All these data confirm the major role of muscle isometric loads on energy expenditure and therefore on HR when driving an open-wheel racecar. Speed increase partly influences HR responses with a biphasic pattern: except at the beginning of driving activity, speed effect appears low if under threshold value and high over there. However, because discrepancies could be observed between HR and speed variations, they also indicate that other factors like road events, psychoemotional factors and environmental factors may exert increasing influence on HR too.

Indeed, chess game produces HR enhancement from 70 to 85 bpm while energy expenditure remain stable (Troubat *et al*., 2009) and bungee jumping is responsive for maximal HR values expression without energy expenditure modification compared to rest level (Hennig *et al*., 1994). Similarly, emotions affect biological values such as respiration rate, blood volume pulse and heart rate through endocrine and autonomic nervous system enhancement. Anxiety was responsive for frequent respiration while sudden stressors (noise, startle) may cause respiration spasm. Pain, hunger, fear or rage are known to affect different aspects of cognition such as goal generation, decision-making, priority setting, focus and attention … and thus indirectly influence performance (Katsis *et al*., 2010). It is now well admitted that all these emotional effects are mediated by sympathetic system activation responsive for vasoconstriction and HR enhancement, while quiet relaxation induced vasorelaxation and low HR.

It is of evidence that driving conditions affect HR response and that HR reacts quite instantaneously and markedly to road events, even at low speed driving. For example, in healthy drivers, low density rural highway driving was shown to produce a HR increase of 20% from resting values while the increase was 28,2% when driving in urban environment, 42,3% when driving in "critical situations" (overtaking, sudden stop…) (Simonson *et al*., 1968). Similarly, mean HR response was approximatively 10 bpm greater (152.1 *vs* 142.0 bpm) on the roadway circuit than on speedway circuit (Jacobs *et al*., 2002). Similar finding were reported in drivers by McKenna *et al*. (1982). Indeed, when drivers are submitted to intense and prolonged stress their thinking, perception and judgments are impaired and progressively tend to be unable to manage one's emotions. Such situations could constitute a psychoemotional stress responsive for HR enhancement. In speedway driving training or competition, pilots perform successive laps of a circuit. Due to the relative similar speed of the different vehicles and the repetitive schedule of the effort, incertitude is low. It relies mainly on driving errors or on overtaking. Moreover, repetition trends and/or endurance training are known to reduce psychoemotional stress and increase psychological capacity and stress tolerance (Konttinen *et al*., 2008). According to these observations, the fact that pilots were engaged rather in training sessions than in competitive race could explain the moderate mean HR values measured (132.71 ± 10.71 bpm; table 2). This idea is also supported by the observation that the highest HR values (143.06 ± 4.97 bpm; Table 2) was obtained during driving bout 1 suggesting both greater motivation and greater anxiety in response to relative ignorance of the circuit.

Heat is one of the main environmental factors that can affect performance driving and HR response (Carneiro Rodrigues and de Castro Magalhaes, 2004; Walker *et al*. 2001). Sweat evaporation may be restricted by the helmet, gloves and the driving suite favoring body temperature enhancement (Konttinen *et al*., 2008). As indicated in the Methods part, subjects observed strict recommendations to limit such an experimental bias and these parameters can be rejected.

Any activity, if performed long enough will render a person unable to maintain skilled performance. In the context of car racing, or even training, driving at high speeds make this situation not tolerable because it compromises performance but endangers drivers' life as well. As reported in Table 2, total driving duration was 121.72 ± 16.73 min but divided in 5 driving bouts of mean 27.81 ± 1.50 min duration, and mean HR values are not significatively different. These results suggest that fatigue plays a major role during our experiment. However, because the lowest HR values (129.12 ± 19.62 bpm) were observed in bout following previous longer resting period (1h30 vs 1h) than in other driving bouts this parameter cannot be definitively rejected and needs further investigations.

In conclusion, the good stability and repeatability of our measurements indicate that HR monitoring is an accurate method to evaluate racecar pilot adaptation to race driving. They show that driving an open-wheel race car on speedway at 135 km/h during over 30 minutes induces an HR elevation to 143 bpm with good repeatability over the 5 driving bouts released. They confirm the major role for muscle isometric loads on energy expenditure and therefore on HR increase when driving. However, stressing factors involved in driving are numerous (environmental, physical, physiological, emotional…) and their interactions are not yet well-known. Because discrepancies between HR and speed variations could be observed in the literature, our results do not allow the evaluation of the respective part of physical demand and psychoemotional factors on HR variations during driving, and this point needs further investigations.

5. Practical applications

Observations on racecar drivers are of interest since car racing may show, at an exaggerated manner, the physiological stress related to automobile driving. The use of small sensors as actimeters (which combined several physiological data; Beaune *et al*., 2010), GPS devices or HR monitors together appears as a good strategy to investigate pilot adaptation to driving during training.

Better understanding of the influence of the different stressors in relation with fatigue development during long term driving for example is also of great interest in security management and accident prevention. What is the most appropriate driving time before fatigue processes significantly affect driving performance in road drivers? Is this parameter similar when driving in the morning or the afternoon? During spring, easter or autumn...?

Competitions induce a high emotional stress. This evaluation needs measurements in laboratories using specific techniques like eye-movements recording and/or facial electromyography (Katsis *et al*., 2010). During a 24h car race, 3 or 4 pilots alternate for driving. What is the influence of psychoemotional parameters on fatigue development during each driving bouts? How long has to be each driving bout to optimize immediate performance or facilitate recovery period after/before driving? What is the best alternation rhythm between pilots for ideal driving bouts management? Due to cockpit exiguity and discomfort of apparatuses, security rules make impossible such measurements during competitions as well as during training. Development of portable and/or integrate systems including physiological parameters allowing both for body adaptation and psychoemotional data (energy expenditure, HR, respiration rate and depth, skin conductance….) could be an opportunity for giving linked and/or pertinent indicators for performance and effort management in standardized situations first, and therefore during competitions.

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