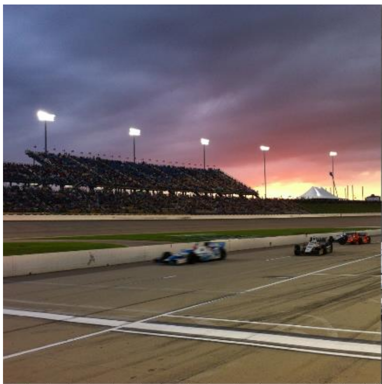
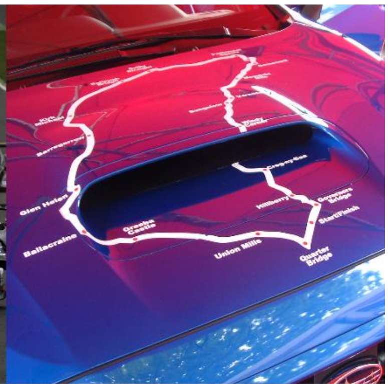
Driver Physiological Monitoring
On-track and in-sync






Measureable Parameters

Heart rate
Breathing rate
Core temperature
ECG
R-R interval
Heart rate variability
Respiration waveform
XYZ acceleration
Exertion
Fatigue
Stress

Why Monitor Vital Signs?

Physiological parameters such as heart rate and breathing rate give important information on performance.

The driver is the most important and valuable component of a car. Racing drivers are subjected to physical and environmental extremes and it is important to understand their physiology in order to improve performance, fitness and driver safety.

Synchronised vital signs information allows teams to make decisions based on driver performance alongside car performance. By understanding man and machine as a single unit it's possible to balance the needs of both to achieve the best lap times.

Wireless Monitoring

The Pilot™ interface wirelessly collects information from a driver-worn physiological monitor. This information is delivered in real-time to the car's on-board management unit. Data is then processed the same as other car parameters and stored or sent out over the car's telemetry so it is available whenever car data is reviewed.

Parameters collected include: heart rate, ECG, R-R interval, heart rate variability, breathing rate, core temperature and g-forces. The Pilot™ interface supports fitness and medical grade monitoring devices and other devices can be added.

Cost Effective and Reliable

The Pilot™ system collects real-time, actionable information on driver physiology whilst seamlessly fitting in with the existing racing infrastructure; without any conflicting requirements for car designers, teams, drivers, engineers or mechanics. This makes introducing a complete monitoring solution both simple and cost effective.

Information must be accurate, available and reliable. Yellowcog's Pilot™ was designed specifically for motorsport and has been proven in some of the toughest races on the calendar, including the Le Mans 24 Hours, open-wheeled racing and long-distance rallying.

Adaptable and Expandable

Yellowcog's Pilot™ system can be fitted to existing vehicle monitoring systems or supplied as a complete package of driver and vehicle monitoring. By monitoring the driver and vehicle together the quality of both can be improved. Every aspect of the vehicle can be logged or transmitted alongside the driver data.

Yellowcog's Mission

"Yellowcog is committed to providing real-time physiological monitoring for drivers at all levels of motorsport. All aspects of vehicles are monitored and we believe the same attention should be given to the driver. In the event of crash we currently have the situation where the engine's RPM is known but the driver's BPM isn't. The more routine monitoring that's carried out, the more that's mandated, the greater the gains in performance and safety for the athletes who participate and risk their lives."

Marc Smith, Managing Director

Safety

Motor racing is inherently dangerous and any accident presents medics with a potential life-and-death situation.

Seconds are extremely valuable; providing real-time information to the course medics, either direct or relayed by the team, means that while on-route to the crash site they can make informed decisions about whom to treat and how. Having access to driver vital signs from previous races allows doctors to better understand recovery progress.

When a driver crashes they are subjected to major g-forces. The assumption is always made that a driver may have spinal injuries. Giving medics the real-time vital signs information means they can balance the speed of extraction against the urgency implied by the vital signs.

Contacts

For information or support, please contact us at:

info@yellowcog.com
+44 (0)7525 133409

Or visit us at:
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twt: @yellowcog

Optional Parameters

EEG (brain)
EMG (muscle)
Eye tracking
XYZ rotation
Photopleth' (PPG)
Blood oxygen (SpO_2)
Blood pressure

Case Study – Driver Safety

Yellowcog designed the Pilot™ system with safety as our primary objective. We tested the system in the East African Safari Classic Rally in Kenya; the course medics were able to monitor drivers' vital signs in real-time from the medical helicopter. The importance of having such physiological information was shown when a car hit an obstacle and barrel-rolled. The drivers both escaped serious injury but the changes in the physiological data in the moments after the accident were dramatic. This sort of information is important in tailoring the response of the medics, for example by prioritising the person most in need. Having such information in the seconds before arriving at the scene makes a huge difference to the treatment.

Performance

Sport is now more competitive than ever before. Motorsport is one of a few sports where regulations and financial constraints limit the time a driver can train in the target environment. As such, it is important that the simulator and training results can be compared to race-day performance. Without timely comparisons in performance, the time taken to improve is unnecessarily lengthened.

To improve track performance it is essential to know exactly how the driver is performing during the race. Having this information in real-time allows a team to adapt to conditions as they change.

Every race is different and a driver's psychological and physiological responses cannot all be predicted in advance. By receiving continuous information on the driver's state it is possible to balance the needs of the driver and vehicle. The team's tactical decisions can be made with a complete picture available.

There are many situations where driver information can lead to a better team decision. Endurance drivers who are fatigued make mistakes that could cost the race, drivers past safe physiological limits become a danger to themselves and others - individuals are generally not aware of these limits until they are crossed. There are many tactics to deal with these situations, for example instructing them to ease-off for a time in order to recover and regroup.

Race Reports

Yellowcog's software library allows data from many different sources to be combined and analysed – either in real-time or from recorded data. The Race Report provides key parameters and statistics summarising the driver's state.

Information collected from every training, simulator or race session is delivered in a succinct and intuitive Race Report to provide a complete snapshot of the physiological performance. The reports are cumulative and provide a record of performance change race by race.

Pushing Past the Limit

Motorsport is operating at the extreme limits for both the car and the driver. Every athlete has a threshold beyond which the body cannot sustain that level of intensity. Exceeding this limit requires a finite amount of time to recover. Finding the driver's limits can be done in the gym but only by monitoring in the race and in real-time can the driver's track performance be fully understood. A driver exceeding their limits on a complex of corners is less able to carry out an overtaking move during the recovery period. This will only become apparent with routine monitoring. Alternatively: did the driver brake late because he made a misjudgement? Was that misjudgement caused by mental or physical fatigue? Real-time monitoring can allow a team to use this information tactically just as brake temperatures may be managed.

Information collected from drivers shows that physiology is very variable driver-to-driver and also during a single lap. Drivers are not constantly "at the limit"

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as is often assumed. Our information is used to inform driver training by preparing them for the “load terrain” that they will experience on each specific racing circuit. This makes the information useful and relevant.

Case Study – Overheating

Going beyond the body’s limits is not always apparent to the driver. A recent example is of a driver who, due to environmental conditions, was overheating with the result that lap times were suffering. Cooling to the car was improved during the race with the result being the driver’s core temperature reduced and lap times improved. Without knowing that physiology was a factor, the race would have been compromised.

Vital Signs

The myriad processes in the human body are all interlinked and kept in equilibrium by homeostatic mechanisms. The body’s base stable state is upset by internal and external stresses: environmental, physical, chemical and psychological. All the vital signs are interrelated e.g. a rise in temperature causes lower blood pressure which in turn raises heart rate which in turn alters blood oxygenation which causes changes in breathing. All these cause-and-effect relationships occur in many different combinations making it impossible to make definitive statements about which was the driving force without looking at all the parameters in unison. By measuring a core set of vital signs we can calculate the load that the body is under – the better able to cope, the better an athlete’s performance.

Measuring vital signs is the only way to understand where the driver is performing compared to safe and sustainable maximums.

Data Fusion is used to combine multiple vital signs into simpler forms. Our increasing body of knowledge on racing drivers has allowed us to use data fusion techniques to take the complex physiological data and produce stress and exertion indices that are plotted on a live map of the circuit to provide an intuitive summary of the driver’s condition. This means that medical and non-medical team members have the same top-level view while still allowing for detailed analysis of the driver’s physiology.

Electrocardiography (ECG) is used to monitor the heart by using a chest strap with conductive electrodes. The heart is a muscle and all muscles in the body give off small electrical signals as they contract. When measuring across the chest the electrical signal of each heart beat is detectable. However, the signal gets noisier if there is a lot of body movement for two reasons: the electrodes are being physically disturbed and the other muscles’ electrical signals combine with the heart’s signals. Techniques have been developed (heart monitoring was invented over 100 years ago) to minimise the effect of noise. Quality ECG is the key to calculating many other parameters that show the physical and, importantly, mental state of the driver.

Heart Rate is measured in beats per minute (BPM) and is derived from the ECG. To get the heart rate in beats per minute, the ECG pulses are counted over a short period of time (say 15 seconds) and multiplied up to the full minute. The result is a heart rate signal that smoothes out noise and abrupt changes; more detailed analysis of the ECG signal is also carried out to get the spontaneous heart rate and beat-to-beat intervals and variations.

Heart rate is an indicator of the physical load a driver is experiencing. Age and fitness govern the maximum achievable heart rate; taking the measured heart rate as a percentage of the maximum shows how close the driver is to the limit.

Heart Rate Variability refers to the natural variations in heart rate which are driven by the interrelated processes of the body. Variations referred to as respiratory sinus arrhythmia are caused by inhalation and exhalation and map to

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Pilot™ Interface

Provides data in industry standard formats: RS-232, CAN Bus and Analogue.

The interface integrates with all major ECU/EMU brands and types.

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the breathing frequency; changes in arterial blood pressure cause lower frequency oscillations; higher frequency oscillations are caused by other aspects of the nervous system. It is important to carry out the analysis in both the time and frequency domains to produce a set of understandable and comparable results and visualisations.

Most variations are small in magnitude but vary greatly in frequency. Variability can only be calculated from either high sample-rate ECG (ideally 1 kHz) or high precision (millisecond) beat timings. The beat intervals are analysed to produce a range of parameters and visualisations indicative of the effect of the various systems of the body.

Breath Waveform is measured using the same chest-worn device as is used as for heart rate. The body functions by a complex set of interrelated processes. Breathing in oxygen would seem to be irreducibly simple but oxygen uptake is only a small, albeit vital, part of the picture. Breathing is equally the method for removing carbon dioxide (CO_2) from the blood. CO_2 is a by-product in the tortuous chain of chemical reactions that power our bodies and is the chief determinant of blood acidity (pH). When we look at the breathing rate around the track we are seeing how the physical effort requires more metabolic reactions forcing higher oxygen intake and increased removal of waste CO_2. It is possible (using an augmented version of Yellowcog's system) to directly measure the O_2 and CO_2 transfer by sampling the air being breathed. We measure breathing waveform in two ways: the physical change in the chest size and a technique known as impedance pneumography. Measuring the physical change in chest size is the most intuitive and accessible. This can be done by absolute measurement (as you might with a tape measure) or by relative change. Relative change is the most common as you can detect this just by measuring the force the chest expansion has on the strap. As the chest inflates it has to slightly stretch the chest-strap so the force increases. When the chest deflates, the force on the strap weakens. By spotting the maximums you detect each full breath. The second way of measuring breathing is by a technique called impedance pneumography. This puts a small electrical current through the chest via the ECG electrodes. As the lungs expand the chest cavity fills with air which changes the resistance between the electrodes. This can then be measured giving the same sort of relative chest expansion waveform as other methods. The breath waveform is too dense a dataset to see patterns at anything but the closest scales – but at close scales it is possible to see the breathing pattern corner-by-corner.

Case Study – Breath Holding

A driver is subjected to g-forces and it can feel natural to hold the breath to brace the body. We monitored a driver who was found to hold his breath on every high-g corner. This has a deleterious effect on the body and requires more rapid breathing away from the corners. When corners were chained together, or the driver was in contention with another driver, then the hold-and-brace method caused disturbed breathing throughout the lap. A driver is easily trained to breathe correctly with the appropriate real-time feedback.

Breathing Rate is measured in breaths per minute and is derived from the breath waveform. The breath waveform shows the expansion and contraction of the chest. Peak to trough and back to peak is one breath.

A constant breathing rate is an indication that the driver is in a stable and sustainable state. The breathing rate can be used to analyse if the driver exceeds the ventilatory threshold. This threshold is related to the lactate threshold and is indicated by a sudden rise in breathing rate. Passed this point the driver is producing lactic acid which will impede performance and require time to recover.

Core Temperature is measured in Celsius and is calculated by using published medical algorithms to estimate

Future Proof

The Pilot™ platform is being continually expanded to add support for more monitoring devices and vehicle systems.

core temperature. Core temperature is a vital indication of the body's health. 37 degrees Celsius is often cited as the normal core temperature but it varies from person-to-person, how it is measured and even the time of day.

What is more interesting is the change in temperature. Over a period of six hours, a normal adult may vary by half a degree or more. So the maximum normal rate of change, all other things being equal, would be roughly a tenth of a degree per hour. Exercise causes the core temperature to rise as heat is generated in the muscles of the body – the body's regulatory systems must ensure that the absolute temperature stays within healthy limits. A combination of factors including physical workload, reduced cooling (fireproof overalls), increased ambient temperature (cars generates heat) and psychological factors (such as danger and excitement) are known to increase body temperature.

G-force accelerations are measured on three axes: vertical, lateral and sagittal. The strength and duration of these accelerations are important for strength training. It is well known that great neck-strength is required to sustain multi-g cornering. Strength must be augmented by the physical ability to counteract the jerk forces (the rate of change in acceleration). Accelerations and jerk forces interact with the physiology of the driver; by measuring the g-forces experienced by the driver (and not just the car) changes of physiology can be understood in context.

Angular rotational forces, measured with a three axis gyroscope, can be measured to supplement the directional accelerations. The three axes rotational accelerations are experienced by the driver as additional physical loading, particularly on the neck muscles.

G-forces are also important in analysing accidents. Racing accidents have created transient g-forces of over 100g. Sudden changes in angular speed are especially dangerous as they cause sheer forces between the brain and skull. The effects of a crash on the body are poorly understood, in part due to a lack of data. Data, physical and physiological, after a high-g impact is not only valuable in the immediate treatment and rehabilitation for the driver but also to help improve motorsport safety for all other drivers. For example, the incidents of (basilar) skull fractures caused by high-g negative accelerations led to the development of the HANS device.

In Summary

Vital signs analysis is the only way to understand how hard an athlete is working and hence how close to the limit they are. Exceeding maximum physiological limits temporarily is possible but at the cost of having to then reduce below the maxium in order to recover. Knowing the exact performance of a driver, in real-time, allows the optimum level of performance to be maintained.

Contacts

For information or support, please contact us at:

info@yellowcog.com
+44 (0)7525 133409

Or visit us at:
www.yellowcog.com
twt: @yellowcog

Yellowcog is a British limited liability company. Our registered office is:

Yellowcog limited
1 Viaduct Cottages
Hurstbourne Priors
Whitchurch
Hampshire
RG28 7RS

Company Number: 07392789, VAT: GB 100277758,
EORI: GB100277758000, WEEE: WEE/BJ2888SV