Eye tracking and cardiovascular measurement to assess and improve sporting performance

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Why are Eye Tracking and Cardiovascular Measures Useful in Sport?

One of the difficulties of working in applied sports psychology is the lack of objective data to help understand the psychological components of an athlete's performance (Watson & Coker-Cranney, 2018). This may be one of the primary explanations for the disparity between how important coaches and athletes report psychological elements of elite performance and how much they invest in tracking and supporting such elements (Pain and Harwood, 2004). In this chapter, we discuss two objective psychophysiological measures which provide valuable insight into the psychology of performing under pressure in elite sports, and can address the need for objective data to support athlete performance. Both measures – eye tracking and cardiovascular reactivity – have considerable evidence underpinning their efficacy in research environments (e.g. Kredel, Vater, Klostermann, & Hossner, 2017; Moore, Vine, Wilson, & Freeman, 2012). We discuss some practical issues that require consideration when using such measures in applied sports settings and report a case study. Combining these measures enables an in-depth and objective investigation into the complex interplay between visuomotor and physiological factors in the sporting environment.

Eye Tracking

In dynamic and unpredictable sporting arenas, athletes must be able to identify and process only the most important visual information to support successful decision-making and motor actions (Mann, Williams, Ward, & Janelle, 2007). It is therefore unsurprising that mobile eye-trackers have frequently been applied in sporting environments to understand the perceptual and attentional mechanisms that underpin sporting expertise (see Moran, Campbell, & Ranieri, 2018 for a recent review). Identifying the optimal gaze behaviour for a

given skill serves as a conceptual tool for applied work because such models can be used to train athletes to adopt optimal gaze behaviours and detect deviations from expert gaze behaviour to help troubleshoot any problems.

One particular gaze strategy termed the ‘quiet eye’ (QE; Vickers, 1996) has been identified in many sports and is proposed to reflect a critical period of cognitive processing during which task relevant environmental cues are processed and motor plans are coordinated (Vickers, 2007). An earlier QE onset (i.e. the starting point of this gaze strategy) and longer QE duration has been consistently observed in expert athletes and prior to successful outcomes (see Lebeau et al., 2016, for a recent meta-analysis and review). This finding has led to the effective introduction of QE training interventions, which utilise eye tracking to improve athletes’ performance by providing feedback about their gaze behaviour in relation to an expert model (e.g., Harle & Vickers, 2001; Lebeau et al., 2016; Vine, Moore, & Wilson, 2011).

A key characteristic of elite athletes is that they must maintain this control of attention in pressurised and fatiguing environments (Wilson, 2012). Another common application of eye-tracking in sport is, therefore, to investigate how gaze behaviour (e.g., the QE) changes when an athlete feels anxious or fatigued. The QE reflects goal-directed control of attention, something which elite athletes must maintain in pressurised and fatiguing environments to avoid performance breakdowns (Wilson, 2012). QE durations have been shown to decrease under pressure (e.g., Causer, Holmes, Smith, & Williams, 2011; Vine, Moore, & Wilson, 2013) and physiological fatigue (Wilson, Webb, Wylie, & Vine, 2018), with subsequent detrimental effects on performance. Such research further highlights the efficacy of using eye-tracking as an objective index of psychological processes which are determinants of performance outcomes, yet are inaccessible through athlete reports or coaches’ observations.

Cardiovascular Measures

The sporting arena provides a perfect environment in which to explore the effects of pressure on performance: some athletes rise to this pressure while others collapse. These diverging outcomes may be driven by different evaluations and responses to the stressful stimulus. The Biopsychosocial Model of Challenge and Threat (BPSM; Blascovich, 2008) is a theoretical framework that explains how individuals respond differently to pressure. Under pressure, individuals evaluate the demands of (e.g., task difficulty) and resources available (e.g., skill level) to complete a task. When perceived resources outweigh demands a challenge state is experienced, whereas when demands outweigh resources, a threat state is experienced. This cognitive evaluation has effects on the physiological stress response, resulting in distinct cardiovascular profiles which can be used as objective indices of challenge and threat states (Seery, 2011).

As challenge states are associated with better performance outcomes than threat states (see Hase, O'Brien, Moore, & Freeman, 2018 for a review), cardiovascular measures can be utilised to predict subsequent performance. Importantly, athletes can be trained to make more productive appraisals; either by positively reinterpreting heightened arousal as beneficial for performance, or by developing their coping resources to counteract particularly threatening stimuli (Moore, Vine, Wilson, & Freeman, 2015).

To summarise, the assessment of the objective, psychophysiological measures we have highlighted – both eye tracking and cardiovascular – has two main benefits for the applied practitioner working alongside coaches and technical support staff:

1. They provide insights into the current mental state of the athlete and can be used to predict how performance will be influenced under pressure.
2. They can be used directly to support targeted bio-feedback training to improve performance under pressure.

However, as with all psychophysiological measurements, there are a number of practical considerations to note before deciding whether to adopt in applied practice.

Section 2: Practicalities of Eye Tracking and Cardiovascular Measurement Techniques

Eye Tracking

Current mobile eye-tracking devices consist of glasses with miniature cameras mounted on the frames to record an individual's eye-movements during the performance of 'real-world' motor skills (see Panchuk, Vine, & Vickers, 2015). To simultaneously capture the visual environment in front of individuals and localise their gaze in that field of view, a scene camera is mounted on the front of the glasses. Infra-red light is directed towards the eye to illuminate the pupil which causes reflections from the cornea that are used to determine the position of the eye relative to the visual scene (Duchowski, 2007).

Prior to data collection, a calibration procedure is performed in which individuals are asked to focus on a series of pre-defined locations to determine where their eyes are in relation to the environment. Practitioners can then view an individual's current gaze location overlaid onto the scene; either in-vivo as the skill is being performed, or retrospectively after the skill has been completed and data have been downloaded. Specific measures (e.g., quiet eye, or percentage of time fixating certain areas of interest) are then calculated via post hoc analysis of the video footage.

Cardiovascular Measures

Impedance Cardiography is commonly used to index cardiovascular reactivity in the challenge and threat literature (e.g. Brimmell, Parker, Wilson, Vine, & Moore, 2019). This non-invasive technique measures beat-to-beat changes in the electrical conductivity of the thorax via electrodes (Newman & Callister, 1999). Cardiac Output is the amount of blood

flow that is ejected from the heart per minute and indicates sympathetic-adrenomedullary (SAM) activation, leading to the release of adrenaline and a subsequent increase in cardiac activity. Both challenge and threat states are characterised by an increase in CO. Threat states are also characterised by hypothalamic-pituitary-adrenocortical axis (HPA) activation which leads to the release of cortisol which dampens the effect of SAM activation thus reducing cardiac activity and limiting dilation of the blood vessels. A challenge-state is therefore characterised by relatively higher CO than a threat state. Total Peripheral Resistance (TPR) is the net dilation versus constriction of the vasculature and is also calculated based on CO and HR estimated from the impedance cardiograph. Generally, a challenge-threat index (CTI) is calculated by converting each participant's CO and TPR reactivity values into z-scores and summing them such that a large CTI value corresponds with a cardiovascular response more akin to a challenge state (Seery, Weisbuch, & Blascovich, 2009). Importantly, these variables are not measured directly and are estimated based on arterial pressure and electrical signals from the heart.

Practical Issues in Data Collection

Using eye-tracking and impedance cardiography in naturalistic sporting environments often requires a trade-off between assessing the skill in the most ecologically valid way, and reliably capturing the data. In this section, we outline some challenges faced when using these measurement techniques in sport.

Calibration. Calibration refers to the process in which the eye-tracker determines where a participant is looking in relation to the visual environment. This process is extremely important because the quality and accuracy of the subsequent data collection is largely dependent on the accuracy of calibration (Duchowski, 2007). Due to the variety in eye-trackers, there are limited standard operating procedures regarding the evaluation of calibration, when to re-calibrate, and when or how to correct calibration problems post-hoc.

Current best practice is therefore to follow the guidelines for the eye tracker being used.

Another consideration is that, while calibration could be perfect, individuals can use their peripheral vision, which is not recorded from the eye-tracker, to successfully execute the task.

For example Croft, Button and Dicks (2010) reported that some cricket batsmen rarely foveated the ball but were still successful at executing the task. Consequently, while eye-tracking provides a window into how foveal vision is being used during a sporting task it cannot measure the use of peripheral vision or covert attention.

Sporting Environments. To obtain the most realistic data, researchers want to test athletes in dynamic and naturalistic situations that closely mimic the complexity of the sporting arena. However, movement and sweating of athletes can be problematic for accurate data collection. Eye tracking glasses can move and electrodes from the impedance cardiograph can become displaced which results in inaccurate or missing data. Researchers often fail to consider these periods of missing data in their analysis which leads to potentially inaccurate conclusions being drawn. Importantly, cardiovascular variables relating to challenge and threat must be taken *prior to performance* whilst athletes are seated, so as not to be confounded by activity level. Hence the CTI is not appropriate as an online measure for active sporting tasks, and may not be capturing the indices of psychological pressure as they are happening. More specifically for eye-tracking methods, changes in light conditions should be considered. Sunlight can interfere with the corneal reflection utilised to track the eye which can contribute to inaccurate data (Discombe & Cotterill, 2015). Such issues can be overcome by anticipating them prior to data collection and developing modified protocols.

Processing Data. The data collected from eye trackers and impedance cardiography requires extensive pre-processing to enable the extraction of meaningful information from very rich data sets. Given that the scene is constantly changing in real-world settings, automatic processing of eye movements (as used for computer-based tasks) is usually not

possible. Instead, videos are extracted and analysed on a frame-by-frame basis, which can be time-consuming and is somewhat subjective (Venker, Pomper, Mahr, Edwards, Saffran, & Weismer, 2019). Consequently, assessments of inter-rater reliability are considered good practice. At each frame, researchers can extract the location of gaze relative to the scene and this can be interpreted (spatially and temporally) to allow for the identification of different gaze behaviours (e.g., fixations, saccades and smooth pursuits; see Discombe & Cotterill, 2015).

Often researchers will identify regions of interest (ROIs) and record when and how frequently gaze is located in such regions throughout a given time period, or the order in which these ROIs are viewed to gain insight into what information individuals prioritise to make decisions (e.g., Moore, Harris, Sharpe, Vine & Wilson, 2019). For other tasks, we may be interested in where gaze is located before a critical movement to understand how vision supports movement planning or control. This vision-in-action approach (Vickers, 2007) requires video showing the motor behaviour (often a side-on view of the performer) to be synchronised with the gaze behaviour video for further analysis of QE variables. In both cases, there might be certain points during the video that are more revealing than others, and it is up to the practitioner to ascertain these most meaningful timepoints through some form of task analysis. Since this processing and data extraction is subjective, this should be done via discussions with the athletes and coaches to determine the crucial components of data for further analysis or processing.

Practitioners have control over several parameters when using impedance cardiography that will influence subsequent processing. When faced with a large data set, practitioners must decide which time-points are most important and how to pre-process the data (e.g., filtering) because cardiovascular data is typically quite noisy. In addition, there is commonly missing data from such measures so analysis plans should be pre-determined and

clearly specify how to deal with periods of missing cardiovascular data (e.g. exclusion, interpolation).

Athletes' Engagement. A critical aspect of utilising evidence-based practice within sports is that the coaches, athletes and support staff must engage in the process and see potential value. Therefore, prior to the development of any protocols, it is important to engage in extensive discussions with athletes and coaches so that they are involved in the planning process and understand the relevance from their own perspective. Developing a language that both coaches and athletes can understand is essential in the feedback stage of applied work. Using videos to clearly illustrate how an athlete's behaviour changes during different components of a project and audio feedback with figures enables them to fully understand the results of projects and how these can be used to improve their training practices. Moreover, engaging with athletes can be fruitful in identifying subsequent projects to further explore how performance can be enhanced.

Using Eye Tracking and Cardiovascular Measurements in the Sporting Arena

Despite a wealth of experimental research aiming to disentangle the relationship between emotional states, gaze behaviour and expertise, there has been limited use of these tools by practitioners working directly with athletes. The case study below highlights the use of eye-tracking and impedance cardiography for objective measurement of psychological aspects of performance in an applied sporting setting. We will highlight the benefits of utilising these tools to provide coaches and athletes with reliable insights into an athlete's psychological state (see Panchuk, Vine, & Vickers, 2015). Case studies are an effective way to obtain a large amount of data on a particular athlete that can then be evaluated collaboratively between coach and athlete to help improve performance (Anderson, Mahoney, Miles & Robinson, 2002).

The following section details a case study from the combined run-shoot event of Modern Pentathlon. In this final event of the competition, athletes complete four laser shoots (each requiring five successful target hits) and four 800m runs. There is a staggered start, with the individual with the most cumulative points prior to this event (i.e. from the swim, dressage and fencing) starting a given time before their competitors and, therefore, the first athlete to finish the combined run-shoot wins the overall event. As Modern Pentathlon is a multi-event sport, athletes are extremely fatigued by the fifth event which can result in pressure-induced breakdowns in decision making and attentional control. Therefore, eye-tracking and impedance cardiography might provide individual insights into the effects of fatigue and psychological pressure on performance, and provide data to support targeted feedback and interventions to improve athletes' performance under pressure.

Aims. Athletes commonly compete in pressurised and fatiguing environments. This case study explored how visuomotor control and performance were affected when Modern Pentathletes completed a run-laser shoot task under a combination of these factors. We aimed to identify the conditions each athlete found most challenging and suggest training practices to facilitate optimal visuomotor control and performance.

Data Collection. Twelve athletes completed a combined run-laser shoot task in four conditions: a matrix of low and high pressure and low and high fatigue (see Figure 1). We manipulated fatigue by modifying the pace at which athletes completed an 800m run prior to the execution of the shooting task. We introduced psychological pressure via instructions designed to induce social-evaluative threat. Specifically, in the low pressure conditions athletes were told that we were calibrating the equipment and checking that data was being accurately recorded. In the high pressure trials, athletes were told that they were in a competition against each other and that the data was being recorded for a documentary. Both

subjective and objective indexes revealed that the pressure manipulations were successful. Impedance cardiography measures were collected prior to the run-shoot task, and shooting performance metrics, and eye-tracking collected during the task. Cardiovascular variables were combined into a CTI (see Seery, 2011) to gain insight into each athlete's response to the pressurised situation.

Condition 1 Low Pressure, Low Fatigue	Condition 2 Low Pressure, High Fatigue
Condition 3 High Pressure, Low Fatigue	Condition 4 High Pressure, High Fatigue

Figure 1. Diagram to demonstrate the four environments each athlete completed the run-laser shoot task in.

Results and Conclusions. Data from the baseline condition (i.e. low pressure, low fatigue) enabled the development of a model of visuomotor control in laser shooting (Figure 2). This model was generated to provide a 'point of reference' demonstrating the most optimal visuomotor strategy for athletes. On arrival to the shooting gates, athletes grip the gun and raise the arm towards the target. On the first shoot of a series, during this gun acceleration, they fixate the aiming zone which defines the start of the QE period. During this QE period, athletes' gaze should remain stable on the target whilst they extend and then lock out the elbow and wrist. Athletes then squeeze the trigger, which marks the end of the QE period (i.e. the execution of the critical motor action).

Figure 2. Schematic diagram of the model of visuomotor control in laser shooting

Quiet eye. We first looked for overall trends in the data by considering all athletes together. There was a difference in QE durations across the four conditions which shows an overall effect of pressure on visuomotor control, but no real effect of fatigue. Specifically, when under high pressure (i.e., Condition 3 and Condition 4) athletes executed a shorter QE for hits compared to low pressure conditions (see Figure 3, Panel A). When averaged across all athletes, poorer performance was also revealed in the high-pressure compared to low pressure conditions.¹

Several theoretical models have been proposed to explain this relationship between anxiety (i.e., an emotional response to pressure) and performance. We drew on the predictions of Attentional Control Theory (Eysenck, Derakshan, Santos, & Calvo, 2007) to suggest that the disruptions to QE and performance that we observed were likely the result of attentional resources being directed away from task execution and towards distracting stimuli (e.g. worrisome thoughts) as a consequence of feelings of anxiety. We suggested that such

¹ Note that these conclusions were drawn from observation of the descriptive data, and no statistical analyses were performed on the data.

disruptions in attentional control are evidenced by an inability to maintain the longer QE durations required to ensure ‘hits’. In this way, we are able to show the athletes and coaches that our interpretation of their data is supported by theory, which can increase engagement and confidence in the utility of subsequent interventions or training practices.

Figure 3. A) Hits and Misses for all athletes across the four conditions; B) Individual data for two athletes who displayed shorter QEs in the high pressure condition; C) Individual data for one athlete who displayed shorter QEs in the high fatigue conditions.

Since individuals respond differently to fatigue and pressure, each athlete’s data was scrutinized independently. Figure 3 (Panel B) shows two athletes who demonstrated large reductions in QE from the low to high pressure conditions, suggesting they were

predominantly affected by pressure. Meanwhile, another athlete displayed reductions in QE from low to high fatigue conditions, suggesting that their gaze behaviour was largely affected by fatigue (Figure 3, Panel C). This highlights the differing response of individual athletes and, therefore, the need for bespoke, personalised training programmes to be developed. Specifically, this project enabled us to identify training conditions in which each individual should practice their run-laser shoot to facilitate the development of optimal visuomotor control for competitive situations. Understanding how attentional control changes in different environments using the objective data served as a catalyst for athletes and coaches to develop individualised, evidence-based interventions in preparation for upcoming competition.

CTI. Cardiovascular markers were also recorded to investigate athletes' physiological response to pressure. Specifically, a CTI was calculated by combining indices of CO and TPR. Figure 4 shows that most athletes (7/11) displayed a more threatened (i.e. a more negative CTI value) response following the pressure instructions indicating that the pressure manipulation was successful and a suitable protocol that can be applied to other sports. Specifically, in the low pressure condition, most athletes were in a more 'challenge' state (i.e. a more positive CTI value) where they felt equipped to cope with the demands of the task whereas after the pressure instructions, most athletes entered a more 'threat' (i.e., negative value) state and evaluated the demands of the task as outweighing their available resources.

We explored the relationship between CTI and performance (i.e., the number of attempts need to successfully hit five targets in the run-laser shoot task) to examine the hypothesis that a 'challenge' state typically leads to better performance (Seery, 2011). Again, there were clear individual differences, which further reinforces the need to consider each athlete as an individual instead of exploring group level data. For example, two athletes became more 'threatened' in the high pressure condition but experienced different performance consequences. Athlete 1 displayed poorer performance, a result that fits with

most research in this area. In contrast, Athlete 2 displayed superior performance despite being more threatened under pressure, which is proposed to reflect this athlete appraising the symptoms of pressure which are represented in cardiovascular markers (e.g. butterflies, increased heart rate) as facilitative for the sporting task which ultimately led to improved performance (see Figure 4 below).

Figure 4. Challenge-threat index to demonstrate how athlete's physiological response changes under conditions of low and high pressure.

Feedback is a critical component of applied work. Immediately after each athlete completed the protocol they were debriefed about the aims of the case study. Following data analysis, a group feedback session was held to discuss the efficacy of using these measurement techniques (e.g., how much data was successfully acquired) and an overview of the results at a group level. This also enabled open discussion between athletes, coaches and other support staff (skill acquisition / performance analysis practitioners) to identify avenues for future exploration. Finally, feedback specific to each athlete (including video feedback)

was given to coaches to facilitate the development of training protocols to incorporate these findings into practice and ultimately improve the athlete's performance.

Conclusions

Eye tracking and impedance cardiography are effective, relatively cheap and non-invasive techniques that practitioners can use in applied sporting settings to gain valuable insights into athlete's visuomotor control and cardiovascular reactivity. This chapter outlined the benefits of obtaining objective data that can provide insight into the psychological state of athletes in applied settings. The case study clearly demonstrated the value of using such techniques to collect large volumes of data that enable individualised, in-depth insights into athlete's performance. We also discussed the challenges of utilising these techniques to highlight factors that require consideration prior to data collection, with a view to supporting practitioners who wish to implement objective measures more effectively in an applied setting.

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