The contribution of cardiac vagal activity on peripheral perception under pressure

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Abstract

The aim of this study is to explore the contribution of cardiac vagal activity (CVA), derived from heart rate variability (HRV), on peripheral perception under pressure. Forty-nine participants (n= 49) completed a peripheral perception task under pressure. Peripheral perception was measured via the Vienna system from which total field of vision was derived. CVA measurements were taken at baseline, during the task and post-task for five minutes along with subjective self-reported stress ratings on a visual analogue scale (VAS). Post task perceived pressure and motivation measures were taken in order to check for pressure manipulation and motivation to compete. CVA measures were inputted as independent variables into a stepwise liner regression in order to predict field of vision. Results showed there were no predictors for total field of vision, indicating that CVA does not significantly affect peripheral perception. Suggestion for null findings are discussed in light of the neuro-visceral integration model.

Key words

Cardiac vagal activity, heart rate variability, peripheral perception, pressure

Introduction

Baumeister (1984, p.610) defines pressure as 'a factor or number of factors that increase the importance of performance at a significant time and/or competition'. Athletes face immense pressure when competing and this can influence many areas of an athlete's performance. One emerging variable of interest under pressure is cardiac vagal activity (CVA) which can influence an individual's emotional regulation, executive functioning and self-regulation (Thayer et al. 2009). More research is using this measure in sport specific contexts in order to understand performance under pressure, one context of which has received less attention is vision. Particularly within sport, vision is a gateway for many perceptual-cognitive skills essential to sport, such as extraction of anticipatory cues, visual search and signal detection (Janelle and Hillman, 2003). Many studies have demonstrated the effects of pressure on central vision or gaze (Moore et al. 2012; Vickers and Lewinski 2012; Vickers and Williams 2007), this is unsurprising as the majority of pressure research focusses on tasks that predominantly use central vision such as dart throwing (Mosley, Laborde and Kavanagh 2017), golf putting (Moore et al. 2012) or shooting (Vickers and Lewinski 2012). Some central vision tasks have been used in conjunction with cardiac vagal activity such as dart throwing (Mosley, Laborde and Kavanagh 2017) and visual search (Laborde, Lautenbach and Allen 2015), with mixed findings for performance prediction. However, there have been less endeavours to understand peripheral perception under pressure and the potential psychophysiological influences that may impact this. Therefore, the aim of this study was to evaluate the contribution of cardiac vagal activity on peripheral perception performance under pressure.

Cardiac vagal activity

The activity of the vagus nerve is called CVA which represents the contribution of the parasympathetic nervous system to cardiac functioning (Laborde et al., 2017). Heart rate variability (HRV) refers to the variation in time between heart beats, in particular between 'RR' intervals in the PQRST complex (Malik, 1996). Parasympathetic activity is positively associated with self-regulation, which in sport can be defined as a performer's ability to pursue goal directed behaviours whilst coping with immediate external constraints (Kirschenbaum, 1987). CVA acts as a measure of self-regulation due to the role of the vagus nerve in parasympathetic function as it connects the prefrontal cortex of the brain to the heart (Olshansky et al. 2008). This connection from the prefrontal cortex to the heart helps to enhance cognitive and cardiac regulation which results in higher levels of CVA reflecting effective self-regulation (Thayer et al., 2009).

To understand how individuals self-regulate and function under pressure, single measures at certain times and changes in CVA have to be accounted for. Tonic CVA, which is taken over a period of time to provide an average cardiac vagal activity measurement (Laborde et al., 2017), has been considered a correlate of self-regulation (Thayer et al. 2009; Park et al., 2014). However resting levels of CVA are indicated not to be enough to represent the change in physiological response to stress. Measuring phasic CVA, the change between tonic measurements, has also been considered an important variable to validly detect changes in CVA (Laborde, Mosley and Thayer 2017; Thayer et al., 2012). Within the current research the three R's model will be adopted for cardiac vagal activity measurement which consists of resting, reactivity and recovery (Laborde, Mosley and Thayer 2017).

Cardiac vagal activity and performance

Recent research has shown support for the theoretical models of CVA influence on performance under pressure. Laborde, Furley and Schempp (2015) explored the relationship between 'reinvestment' – the tendency to think too much under pressure - , working memory (WM), and the contribution of HF-HRV (CVA) to WM. WM was measured in a low and high pressure condition, where HF-HRV was the dependent variable. They found negative correlation between reinvestment and WM as well finding that a higher CVA predicted a higher WM performance beyond subjective reinvestment scores in the high pressure condition. These results support the neurovisceral integration model (Thayer et al., 2009). Although this study supports CVA's ability to predict performance under pressure, the WM task did not involve visual demand.

Currently only limited and indirect research surrounding CVA's influence on visual performance exist. Mainly these studies examine tasks that use central vision, which is defined as focussing straight ahead usually to determine exact directional and spatial information (Erickson 2007), through visual search or aiming based tasks. One study examined the contribution of CVA on visual search performance under pressure (Laborde, Lautenbach and Allen 2015). Ninety-six participants had their CVA measured at tonic (baseline and task), and phasic (between baseline and task) levels for a visual search task (concentration grid). The results from this study suggested that visual performance as evaluated via the concentration grid is not predicted by CVA. Another study focussing on a dart throwing task, which utilises central vision was Mosley, Laborde and Kavanagh (2017). The results highlighted that dart throwing performance was predicted by reactivity CVA, essentially the change in CVA from baseline to task. This evidence suggested that the dart throwing was positively influences by a decrease in CVA from pre-task to task) which contradicts the neurovisceral integration model (Thayer et al., 2009), although the predictions of the model only support executive functioning tasks which dart throwing is not. Further results concluded from the study that CVA and attention were linked to 'aiming', which influenced dart throwing performance with better attention increasing dart performance. Therefore, current findings regarding tasks using central vision are mixed and did not take into account peripheral perception as a dependent variable.

Peripheral perception

Peripheral perception is processing information from peripheral visual fields (Erickson 2007) and has been suggested as key to most invasion games (Junior, 2010; Bell & Hopper, 2003; Rovegno et al., 2001). It is also considered a key factor towards overall sporting performance for example in vertical and horizontal vision performance (Williams & Thirer, 1975); handball (Zwierko, 2007); and perceptual skills in soccer (Williams, 2000). The importance of peripheral perception differs between the task demands. For example, if central vision is key then peripheral information is usually irrelevant and can cause distractions which subsequently degrades performance, however if both central and peripheral vision are important athletes need to balance their visual attention between central and peripheral cues (Erickson 2007). Therefore, in order to use peripheral perception effectively, the ability to use selective attention is crucial, particularly under pressure. Selective attention is defined as an inhibitory control of attention that enables us to focus on the stimuli of choice and supress attention to other irrelevant stimuli (Diamond 2013). Naturally, this ability to select the correct information regarding performance related cues is linked to visual search patterns (Muller & Krummenacher, 2006). This ability to select relevant cues has been a focus of previous theory that has examined the effects of pressure on attentional control, with a particular focus on anxiety. Eysenck et al. (2007) postulated an attentional control theory based on Eysenck and Calvo's processing efficiency theory in 1992. It suggests that anxiety, which may be manifested by pressure, impairs attentional control (to relevant stimuli) in performance. Specifically, it implies that peripheral perception performance would decrease under stressful or anxious conditions, due to an inability to select the correct cues for performance (Eysenck et al. 2007).

Research examining peripheral perception under pressure is limited. One study explored peripheral distractions and assessed participant's eye movement in a motor racing task that included flashing lights (irrelevant cues) in the participant's periphery (Janelle and Singer 1999). They found that increases in anxiety lead to a higher fixation counts, higher peripheral distractions and a focus on task irrelevant information. Other findings suggest that peripheral narrowing occurred more often in high pressure conditions than in low pressure conditions, suggesting that task relevant cues in the periphery of participants were omitted when participants experienced more pressure (Easterbrook, 1959). These findings suggest high pressure situations can cause the number of irrelevant fixations can increase (Janelle and Singer, 1999), and relevant fixations can be omitted due to peripheral narrowing and therefore performance decreases (Easterbrook, 1959). The second point could be considered detrimental to athletes who require a wider attentional field in their sport where peripheral narrowing draws attention away from relevant cues. Peripheral narrowing is more likely to occur in novice performers in comparison to elite (Underwood et al 2008; Weltman and Egstrom 1966), due to elite performers ability to selectively attend to performance cues in both central and peripheral vision (Ryu et al. 2013). Although this is still under researched in line with effects the of pressure it highlights the importance of selective attention in peripheral perception.

The ability to use selective attention within tasks that demand central and peripheral attention is crucial and it is well known that CVA can influence selective attention for goal directed behaviour (Park et al. 2013). It has been postulated that vision acts as a gate-way for selective attention which requires cognitive processing of information at the executive level to inform action (Muller and Krummenacher 2006). In addition, the neurovisceral integration model suggests that higher levels of CVA during tasks that involve executive functioning help to improve performance (Thayer et al. 2009). Given that selective attention is considered an executive function (Diamond 2013), it is predicted that higher levels of CVA would positively influence peripheral perception due to an increased ability to select appropriate cues under pressure. As previous research on CVA has only examined its relationship over central vision performance (Laborde, Lautenbach & Allen, 2015), it may be pertinent to investigate the impact of pressure on peripheral perception and how CVA may be related to it. Given the importance of peripheral perception in sport further investigation could provide beneficial insights to sports where peripheral perception is a key attribute to overall performance. Therefore the aim of this study was to explore the contribution of CVA, derived from HRV, on peripheral perception under pressure. It is hypothesized that higher levels of reactivity CVA (difference between pre-task and task CVA) and task CVA will positively influence peripheral perception score.

Methodology

Participants

A power analysis was conducted using G*Power 3.1.9.2 software was used to determine sample size (Faul et al., 2007). Effect size was set to $f^2 = .35$ and based on Cohen's (1988) recommendations alpha error probability was set to .05 and power was set at .8, number of tested predictors was set at five. The calculated output was a total sample size= 43. Forty nine participants (n=49), aged 21.94± 2.09 years, sport science students with

Commented [SL1]: Why? Which study was used to infer this?

Dan I think you had something before – however it needs to be clear which study this has come from

Commented [EM2]: Gender of participants differing experiences in sport were recruited. Participants gave written informed consent and did not have any cardiac diseases or taking any medication that could affect the heart.

Measures

Cardiac Vagal Activity

CVA can be inferred via HRV measurement. HRV was measured through the Faros 180° device (Mega Electronics Ltd, Pioneerinkatu, Finland) was used to measure HRV to derive CVA. Two pre-lubricated disposable electrodes (Ambu VLC-00-5/25, Ambu GmbH, Bad Nauheim, Germany) were positioned just below the right clavicle and on the left side of the chest below the twelfth rib of each participant. The specific device was selected for this protocol as it weighs just under fifteen grams, allowing more comfort, than heavier ECG machines (Laborde, Mosley & Thayer, 2017). Variables indicating CVA were assessed, the first being the root mean square of the successive differences (RMSSD) (Berntson et al., 1997; Malik, 1996). The second was absolute power in the high-frequency (HF) band of HRV, 0.15 – 0.40 Hz (Berntson et al., 1997; Malik, 1996), calculated via both Fast Fourier Transform (FFT). Conducting analysis with multiple variables from both the time and frequency domain helps to improve the reliability of the results found (Laborde et al. 2017). Electrocardiogram derived respiration (EDR) was extracted in order to be used as a variable to control for respiration (Laborde, Mosley and Thayer, 2017). (For the full data set please see the supplementary material).

Stress intensity

To measure stress intensity a visual analogue scale (VAS) was used, participants marked on a one hundred millimetre line with a cross indicating ‘’how stressed they felt at the present moment’’. The scale varied from one extreme of "not at all stressed" to "extremely stressed" at the other (Lesage, Berjot & Deschamps, 2012).

Pressure Items

The pressure subscales were taken from an intrinsic motivation inventory (Ryan, 1982). Four items were rated by participants on a Likert scale ranging between 1 (strongly disagree) to 7 (strongly agree). These items included statements like: ‘’I was anxious while doing the task’’.

Motivational Item

Participants also completed one item indicating ‘’How motivated are you to perform your best in this task?’’ on a six point Likert scale ranging from 0 (not at all) to 5 (very much so) (Mosley, Thayer & Laborde, 2017).

Peripheral perception

Peripheral perception was measured using the Vienna system. Previous studies have used the Vienna system to test peripheral reaction in handball (Zwierko, 2007) and volleyball (Zwierko et al., 2010), showing its application to sport. The system involves a central tracking device and peripheral reaction task. Participants use a dial to track a ball moving horizontally across the screen in front of them, during this tracking task participants must react to lights in their peripheral vision. Lights in the periphery are continuous, however when a straight flashing bar is presented participants must react using a foot pedal, these flashing bars are presented at varying degrees of vision throughout the task. Within the task visual field is measured in degrees and tracking deviation is measures in seconds when tracking was lost (Schuhfried, 2017).

Procedure

The procedure for the study is presented in figure one.

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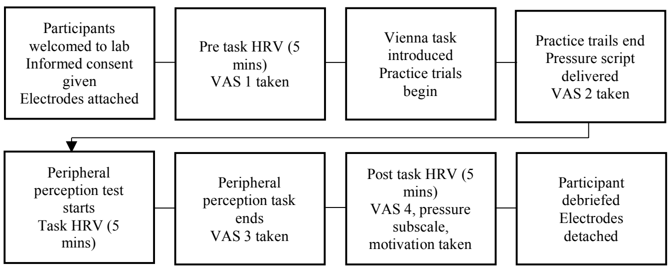

Figure one: Task procedure outline

Pre-task

Participants were welcomed into the laboratory and asked to read the participant information sheet and gave written consent on the day (see Appendix B & C). Participants were then asked to sit in front of the Vienna system to have electrodes placed on them (one under the right clavicle, the other on the left twelfth rib), which were then attached to the Faros device which was then turned on. Following this a baseline measurement was taken for five minutes, where each participant had to be sat knee angle 90 degrees, hands on laps, eyes shut or open with a soft gaze and silent (Laborde, Mosley & Thayer, 2017). Participants were then given the first stress VAS.

Task

Participants were then introduced to the task, this involved a period of familiarization in which they completed practice tasks linked to the peripheral perception test. After the practice had finished an instructional pressure script was read to them before the peripheral test began. The pressure script included stressors such as: being filmed; social evaluation; results being posted on a leadership board at the university; a cash prize for best five performances; interviews with a vision specialist for the worst five performances and the experimenter observing behaviours closely during the task (Baumeister, 1984). The second stress VAS was then administered followed by the beginning of the peripheral perception test which lasted approximately five minutes.

Post-task

After the task had the finished, all subjective measures were given to the participants including a third stress VAS; the pressure items and the single motivation item. The recovery period commenced, with the same standardised procedures as the baseline measure for five minutes. Participants were thanked and debriefed about the true nature of the experiment.

Data processing and cleaning

HRV data was exported to Kubios software for data analysis which is used in most research assessing CVA (Tarveinen et al., 2014). In Kubios artifact correction was performed manually in line with general recommendations (Laborde, Mosley and Thayer, 2017). Following this the five minute intervals for the tonic CVA variables were set in their respective ranges and the values of RMSSD (ms), high frequency fast Fourier transformation absolute powers (ms^2) (HF-HRV), from which reactivity variables were created. EDR was extracted and was multiplied by 60 in order to indicate respiratory frequency (Laborde, Mosley and Thayer, 2017).

Data preparation

All variables were then checked for outliers and were winzorized if any were present using the equation (mean + 2* standard deviations) (Field 2009). They were then assessed for normality, first objectively using a Shapiro-Wilk test and secondly subjectively by observing the histograms and box plot outputs in SPSS. Field of vision was found to be normally distributed, (p> .05), as were of the CVA variables. However some variables were not and therefore all CVA variables were Log10 transformed. The Log10 transformation still elicited some non-normal variables via a ** test (Task RMSSD, p= .045; Recovery RMSSD, p= .000; Pre Absolute Power, p= .002; Task Absolute Power, p= .000; Pre EDR, p= .003; Post EDR, p= .001).

Commented [EM4]: Dan just clarify which normality test these p values have come from

"Do we need a reference for stepwise regression being robust against non-normal variables." – Yes please or at least an inference to it being ok…!

Data analysis

To understand the correlation between tonic and phasic CVA variables a Pearson's correlation analysis was conducted. To control for participant's respiration rates, a paired samples t-test was conducted to check the sample means between pre-task and task. To test for pressure manipulation during the task, a paired samples t-test was conducted between stress VAS 1 (pre-task) and 2 (task). To investigate the contribution of tonic and phasic variables of CVA on field of vision (peripheral perception performance), a hierarchal stepwise regression analysis was performed in two blocks. The first block included age and gender to control for them. The second block was used to explore the contribution of CVA (resting, task, post task, reactivity and recovery) to field of vision. This analysis was repeated for both RMSSD and HF-HRV.

Results

Descriptive statistics are presented below in Table 1 for all variables and correlations between CVA variables are displayed in tables 2 and 3.

Table 1. Descriptive statistics for all variables

Variables	*M*	*SD*
Age	21.94	2.01
Manipulation Checks		
Stress VAS 1	1.23	1.33

Stress VAS 2	2.68	1.69
Stress VAS 3	3.92	1.91
Stress VAS 4	1.24	.92
Pressure	3.96	.70
Motivation	4.22	.74
HRV Raw Data		
Pre-task RMSSD (ms)	45.86	24.03
Task RMSSD (ms)	35.01	12.28
Post-task RMSSD (ms)	42.25	20.50
Reactivity RMSSD (ms)	-7.84	15.58
Recovery RMSSD (ms)	5.68	12.20
HF-HRV Pre-task (ms²)	789.00	684.49
HF-HRV Task (ms²)	460.15	295.77
HF-HRV Post-task (ms²)	711.09	560.74
HF-HRV Reactivity (ms²)	-384.51	591.36
HF-HRV Recovery (ms²)	215.93	366.25
Pre-task RF (Hz)	13.28	2.78
Task RF (Hz)	13.88	1.92
Log10 HRV Data	1.63	.21
Pre-task RMSSD (ms)	1.59	.14
Task RMSSD (ms)	1.61	.20
Post-task RMSSD (ms)	-.03	.21
Reactivity RMSSD (ms)	.01	.21
Recovery RMSSD (ms)	2.77	.42
HF-HRV Pre-task (ms²)	2.58	.37
HF-HRV Task (ms²)	2.78	.39
HF-HRV Post-task (ms²)	-.23	.47
HF-HRV Reactivity (ms²)	.23	.43
HF-HRV Recovery (ms²)	-.66	.09
Pre-task RF (Hz)	-.64	.06
Task RF (Hz)	-.67	.06
Field of Vision (°)	173.15	8.66

Note: RF = respiratory frequency, as calculated by EDR*60 to indicate respiratory frequency

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Table 4. Correlation matrix of RMSSD variables.

	1	2	3	4
1. Pre RMSSD	-			
2. Task RMSSD	.79**	-		
3. Post RMSSD	.87**	.83**	-	
4. Rea RMSSD	-.83**	-.31*	-.71**	-
5. Rec RMSSD	.62**	.34*	.80**	-.65**

**. Correlation is significant at the .01 level (2-tailed).
*. Correlation is significant at the .05 level (2-tailed).

Table 5. Correlation matrix of HF-HRV variables

	1	2	3	4
1. Pre HF-HRV	-			
2. Task HF-HRV	.60**	-		
3. Post HF-HRV	.84**	.58**	-	
4. Rea HF-HRV	-.90**	-.19	-.58**	-
5. Rec HF-HRV	.67**	.17	.86**	-.73**

**. Correlation is significant at the .01 level (2-tailed).
*. Correlation is significant at the .05 level (2-tailed).

Respiration control

The paired samples t-test reported no statistically significant differences between pre-task and task EDR t (48) = -1.71, p= .93, suggesting that breathing was not different between pre-task and task.

Manipulation checks

The paired samples t-test indicated that there was a statistically significant difference between stress scores on stress VAS 1 and 2 which suggests that the participants were significantly stressed t(48)= -6.55, p<.01. The mean score of the pressure check was an average of M= 3.96 SD =.70 out of a possible 5 which indicates the participants were sufficiently pressurised during the study. The mean score of the motivation check was an average of M= 4.22 SD= .74 out of a possible 5 which indicates the participants were sufficiently motivated when completing the task.

The contribution of CVA to field of vision (peripheral perception)

The average field of vision score was found to be 173.2° (SD = 8.7). For both hierarchal stepwise regressions the first block that included age and gender was not found to be a significant predictor. The second block of the first hierarchal stepwise regression model was performed using all of the RMSSD variables. No variables accounted for variance in the field of vision scores. The second block of the second hierarchal stepwise regression model was performed using all of the HF-HRV variables. No variables accounted for the variance in the field of vision scores.

Discussion

The main aim of the study was to evaluate the contribution of CVA on peripheral perception performance under pressure. It was found that for both hierarchal stepwise regressions none of the RMSSD variables or HF-HRV predicted peripheral perception performance. It was hypothesised that CVA and more specifically task and reactivity CVA would predict peripheral perception performance due to the need to use selective attention to attend to peripheral cues. These predictions were support by the evidence suggesting selective attention is an executive function (Diamond 2013) and higher levels of CVA during executive functioning tasks (Thayer et al. 2009). However, in the current study CVA was not found to predict peripheral perception performance.

A potential explanation for null findings could be because the task of identifying stimuli within the periphery alone could be considered as 'non-executive', much like the findings of Laborde, Lautenbach & Allen (2015). Even if the current task, prompting participants to focus on two tasks at the same time (tracking and peripheral reactions) could be considered as more demanding than the task of Laborde and colleagues (2015), the increased demands may have been located more at the perceptual level than at the executive level. Consequently, the current task may not have been demanding enough with regards to attentional inhibition, in comparison to other tasks. For example, Park and colleagues in 2013 used a letter detection task that required participants to purposefully ignore distracting stimuli that were presented alongside relevant cues. They found that higher levels of CVA during the task (high load condition), were better able to select the correct stimuli faster than those with low levels of CVA (Park et al. 2013). This suggests that the need for selective attention was greater and required more inhibitory control, which was facilitated by higher levels of CVA. If the current task was considered to be non-executive in nature, the null findings related to CVA would make sense in light of previous research findings (Mosley et al. 2017; Laborde et al. 2015) and theoretical considerations based on the neurovisceral integration model (Thayer et al., 2009), which postulates that CVA will only contribute to executive tasks (Thayer et al., 2009).

A further consideration could be the role of other subjective variables that may influence CVA and performance, as both Mosley et al. (2017) and Laborde et al. (2015) used coping related variables in conjunction with CVA predictors. For both tasks in these studies subjective predictors accounted for variance in performance such as attention (Mosley et al. 2017; Laborde et al. 2015) and threat appraisal (Laborde et al. 2015). Thus the need to consider subjective variables in addition to CVA is important for future research.

Limitations

One limitation was how peripheral perception performance was assessed. In the present study field of vision was on assessed as the representative dependent variable of peripheral perception. However, in previous research other variables have been used to assess peripheral perception performance when using the Vienna system. Factors such as reaction time; left and right field of vision; omissions and incorrect reactions have also been assessed previously (Zwierko, 2007; Venter & Ferreira, 2004; Ando, Kida & Oda, 2001). Therefore including these variables could provide a more accurate and richer understanding of peripheral perception performance. In addition to this, the Vienna system has come under scrutiny for the lack of standardization of methodologies, which may cause disparities in comparing results between studies (Ong 2015).

When compared to an ecologically valid sport setting, where performers have far more stimuli to react to within a similar timeframe, highlights a lack validity of the present study. This particular issue was highlighted by Ong in 2015 where it is suggested that the test should be directly compared with a similar task which is sports specific in order to draw more ecological comparisons.

Commented [EM6]: What did the other studies you have references using the Vienna in sports found (Zweirko)? Do their findings support or contradict what you are suggesting here?

Conclusion

In conclusion, the present study aimed to explore the contribution of CVA on peripheral perception performance under pressure, hypothesising reactivity CVA to predict peripheral perception performance under the assumptions of the previous similar research findings as well as from the theoretical position of the neurovisceral integration model (Thayer et al., 2009). However the findings of the present research suggested that no CVA variables predicted peripheral perception. This was discussed to occur because of the similarity of the task used in the present study with previous research proposed by Laborde, Lautenbach and Allen (2015) where similar findings could have been due to the non-executive nature of the tasks. This provided further support for the neuro-visceral integration model because it helps to delineate the role of CVA during executive and non-executive tasks. Future research should aim to further test the predictions of the neurovisceral integration model in different contexts that reflect sporting performance, clarify the relationship between peripheral perception and executive functioning in ecological settings and understand the influence of subjective variables on peripheral perception performance.

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