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Understanding the Sport Viewership Experience using Functional Near-Infrared Spectroscopy

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Abstract

Subjective evaluation of a sport event in real time is normally assessed using self-report measures, but neural indices of evaluative processing may provide new insights. The extent of evaluative processing of a sporting event at the neural level may depend on the degree of emotional investment by the viewer, as well as the key moment of the game play being observed. Those with high ego involvement might show more activation within evaluative processing nodes, and this pattern may be most pronounced during critical moments of game play. In the current study, we examined neural activations within the medial and lateral prefrontal cortex during game play as a function of ego involvement, using video clips featuring key moments in a European league ice hockey game. A total of 343 participants were pre-screened to identify high (*n*=11) and low (*n*=9) ego-involved individuals. These subgroups then viewed a game segment containing 12 key play moments, while undergoing neuroimaging using functional near-infrared spectroscopy (fNIRS). Findings indicated more engagement of the dorsomedial prefrontal cortex (dmPFC) throughout all key moments for high ego-involved participants, but particularly during critical game moments. Overall, findings suggest that neural indices of evaluative processing might contribute meaningfully to understanding when emotionally invested individuals are most engaged in an action sequence during a sporting event.

Keywords: fNIRS, ego involvement, sport, spectator, ice-hockey

Introduction

Theories and models of sport consumer behavior often rely on self-reported measures when attempting to understand spectator/viewer experiences [1, 2]. Self-report measures are subject to retrospective biases and lack in-situ perspectives; as well, thoughts and feelings operate at a subconscious-level, and this may not manifest in subjective impressions [3]. Neuroimaging techniques provide researchers with new ways of understanding brain-related mechanisms underlying spectator experiences in a more direct manner [4], but they are also challenging to implement in the context of *in vivo* sporting events. Partially as a function of this, sport consumer researchers have rarely explored how subjective impressions of sport viewership experiences might relate to patterns of brain activation, or what kinds of critical moments within sporting events elicit specific types of brain activity. Functional near-infrared spectroscopy (fNIRS) is a promising solution because of its flexibility and adaptability for in-vivo measurements of brain activity, particularly those that require upright viewing to enhance ecological validity [5, 6 , 4]. We advance the position that measuring brain activity of consumers in the inherently social context of sport event viewing provides access to psychological processes and neural circuitry that guide engagement.

One self-report construct of interest to sport consumer researchers is that of ego involvement, an unobservable state of motivation, arousal or interest toward a sport activity, event, and/or associated product [7, 8]. It is evoked by a particular stimulus or situation and has drive-like properties [8]. Typically, ego involvement is measured in terms of how central a sport is to one's life; and the degree to which the sport (or related behavior or experience) is connected to one's identity [7]. Ego involvement is an important construct in sport consumer research because it has been linked to loyalty, repeat purchase behaviour and satisfaction [9, 10].

Moreover, the ego involvement construct underpins several widely used models of sport consumer behavior and major theoretical perspectives within sport [1].

The purpose of the present investigation was threefold. First, we wanted to examine the viability of fNIRS as a method for assessing neural activity in an ecologically valid, *in-vivo* sport viewership experience. Second, we were interested in examining the extent to which different key moments within a sport event were differentially predictive of changes in brain activity within the neocortex. Finally, we endeavored to examine the extent to which baseline identification with the sport (i.e., ego involvement) moderates the above effects. We hypothesized that: 1) fNIRS will be a feasible method for examining functional brain dynamics during a realistic sport viewership experience, 2) cerebral hemodynamics in the PFC will reveal increases in activation during pivotal game play moments, and 3) these effects would be particularly pronounced for those with relatively higher levels of ego involvement prior to the viewership experience.

A-priori regions of interest included the left and right dorsomedial prefrontal cortex (dmPFC) because of their links to evaluative and self-relevance processing [11,12,13], which could be disproportionately engaged among ego-involved viewers relative to their more neutral counterparts. In addition, the left and right lateral prefrontal cortex (lPFC) were chosen because of links with attentional engagement [14,15], which could arguably be stronger among those with higher ego involvement. Heightened activity in the dmPFC could reflect viewers' emotional involvement in the game action, feeling a sense of connection with a team, or experiencing personal relevance in relation to the game's outcome. Lateral PFC activation in these areas is indicative of working memory and top-down attentional control-filtering out distractions [16].

These processes are essential for following game progress and trying to make sense of the gameplay as it unfolds.

As it relates to the present investigation, we expected to observe heightened evaluative processing and attentional engagement during scoring chances (SC), and other key strategic moments in gameplay such as offensive face-off opportunities (OFO), particularly among those who identify hockey as being more central to their life and identity. For these highly involved ice-hockey viewers, OFO may represent strategic breaks in gameplay, which can serve to cue their attention to something exciting that is about to happen such as a goal or scoring chance.

Moreover, we expected to observe temporal differences in the processing of gameplay between viewers with high and low ego involvement with the sport of ice-hockey. As a game of ice-hockey progresses (during the "early", "middle", and "late" stages), there can be subtle differences in intensity and team strategies as it relates to gameplay. Highly involved viewers may detect these nuances and use time as a means of compartmentalizing the action as it unfolds. The start of the game is often a time for teams to get a sense of the opponent's strategic approach to the game and develop an understanding of their particular tactics (degree of physicality, pressure, speed). However, as the game progresses, teams may attempt to gain strategic advantages and respond to particular tactics in ways that maximize momentum and scoring chances by the end of the period. Highly involved viewers might view the start of the game as their time to observe and make early assessments of gameplay (e.g., which team is performing better). As time passes~~the game progresses however~~, viewers may wane in terms of their attention and emotional involvement depending on the nature and frequency of pivotal (i.e., exciting) moments in gameplay.

Methods

Participants

Study participants were 20 young adults (from a pre-screened sample of 343) between the ages of 18 and 40 (M = 21.84, SD=5.08). The final fNIRS imaging sample comprised those within the pre-defined "high involvement" (n=10) and "low involvement" (n=9) subgroups from the screening phase who agreed to participate in the fNIRS laboratory phase of the study. A table showing demographic and physical characteristics of the final laboratory phase subsample is shown Table 1.

Table 1. Demographics and physical characteristics.

	Ego Involvement Group	
	High (n=11)	Low (n=9)
Sex		
Male	6	2
Female	5	7
Skin pigmentation		
Light	11	8
Medium	0	1
Dark	0	0
Ethnicity		

Caucasian	8	7
Non-Caucasian	3	2
Age	20.50 (2.51)	23.50 (7.25)

Procedures

In an initial screening phase, an in-person survey was distributed to undergraduate students (*N*=343) attending classes at a large University in Southern Ontario, Canada. Those selected from the screening process (identifying those with relatively higher (n=10) or lower (n=9) ego involvement in ice hockey) were invited to attend a laboratory session several weeks later. Upon entry to the lab, participants underwent an informed consent procedure and were seated at a laptop computer. The fNIRS measurement band (containing 16 long channels and 2 short channels) was fitted on the participant's forehead following the procedure described by Ayaz et al. [[18]]. Participants were asked to pull their hair back as the lower sensor strip was positioned just above the eyebrows and the center of the headband was aligned with the vertical axis of symmetry that passes through the nose. Participants viewed a segment of ice hockey play from the Elite Ice Hockey League (United Kingdom) game between the Nottingham Panthers (wearing black) and the Cardiff Devils (wearing red). Prior to watching the game, participants were instructed to choose a team to support. This league and set of teams were chosen because the participants were unlikely to have had prior experience viewing gameplay involving the targets. The play segment (the first 20-minute period of the ice hockey game) was a video clip lasting approximately 25 minutes, including play breaks. At each of the scoring chances and game stoppages (offensive faceoffs), a slice of video segment was cut and presented as stimuli; there were 12 such segments used as stimuli in the imaging portion of the study described below.

This study was reviewed and approved by the University of Waterloo Human Research Ethics Board (HREB; Approval #41286). The study was undertaken in accordance with the Declaration of Helsinki. Informed consent was obtained from all participants.

Design

During the viewership experience we sampled 12 key moments of interest analyzing the mean change in hemodynamic response in the 10 seconds following a scoring chance or a momentum shift in the offensive end. These pivotal moments consisted of scoring chances and offensive faceoff opportunities (OFO) in which a team gained the puck during a face off in the offensive end. The timing of these key moments is presented in **Table 2**.

The 10 seconds prior to each event was used to establish a local baseline allowing us to compare changes in blood oxygenation before and after the events. The 12 key moments used in our analysis are evenly divided into the temporal categories of "Early" (i.e., first four key moments in the period), "Middle" (subsequent four key moments), or "Late" (final four key moments) in order of the viewership experience. Prior studies have reported that differences in prefrontal activation can arise due to fluctuations in arousal [19], or changes in attentional states [20]. As the different levels of ego involvement between the groups may contribute to changes in arousal or attention throughout the 25-minute viewing task we thought it important to consider time as a factor in our analysis.

Measures

Ego Involvement. Ego involvement in relation to watching ice-hockey was used to stratify potential respondents in terms of *a-priori* engagement and interest in the target behavior.

An adapted version of a measure described by Kyle et al. [7] was used. The measure included 15 items regarding the centrality of the target sport (i.e., "[watching ice hockey] is very important to me"), social bonding around the sport (i.e., "[watching ice hockey] occupies a central role in my life"), identity affirmation (i.e., "I identify with the people and image associated with[watching ice hockey]"), and identity expression (i.e., "You can tell a lot about a person by seeing them [watching ice hockey]). Responses to each item were provided using a 5-point scale where 1 = "strongly disagree" and 5 = "strongly agree". Those scoring - 1 *SD* and + 1 *SD* in relation to the overall sample mean were defined as "low involvement" and "high involvement" respectively. The Cronbach's alpha of the 15 scale items was 0.959. Students who participated in the initial screening phase of the study were entered into a draw for a $20 gift card for the University bookstore. Participants in the laboratory phase of the study were given a $5 gift card in reimbursement for time and effort.

Functional Near-Infrared Spectroscopy (fNIRS). Functional near-infrared spectroscopy (fNIRS) uses near-infrared spectrum light emitters paired with sensitive light detectors (optodes) to measure subtle changes in oxygenated hemoglobin concentration (HbO) within the human neocortex [17]. Task-related hemodynamic responses were assessed using an fNIR Devices unit 203c. To measure cortical activation, a fabric band containing the fNIRS optodes was placed over the forehead using anatomical landmarks and fastened with Velcro fasteners. The optodes consisted of 4 light sources and 8 detectors, which combined could produce up to 16 measurement channels, with a sampling rate of 5Hz. Both oxy- and de-oxyhemoglobin were measured. For the purposes of this study, oxyhemoglobin (OxyHB) was measured as the primary metric to quantify neural activation. *A-priori* slices of play action (described above;

n=12 were played on a computer screen in front of each participant while hemodynamic changes in the prefrontal cortex were assessed. For each optode, raw light data were extracted and cleaned using a median filter with a window size of 25 to remove motion artifacts (e.g., head movement) and a low pass filter at 0.1 Hz to remove physiological noise (e.g., heart rate). The 16-channel optode arrangement and experimental set-up are presented in **Figure 1**.

Signal processing and statistical analyses

Optical data was processed using a median filter followed by a low pass filter. This dual-stage approach has been demonstrated as an effective means of filtering both motion artifacts and physiological noise from fNIRS data [21]. The filtered optical data was then used to calculate changes in hemodynamic responses using the modified Beer-Lambert law. Channels [3,4,6] were identified as the left lPFC, channels [5,7,8] the left dmPFC, channels [9,10,11] the right dmPFC and channels [12,13,14] as the right lPFC. We previously found similar identification of the medial and lateral prefrontal cortex yielded good characterization of the underlying structures [22]. The most lateral channels (i.e., 1, 2, 15, 16) were not included in the ROIs as we found their position at the ends of the fNIRS headband made them more susceptible to issues of poor signal quality arising from motion artifacts or light leakage.

Our statistical analysis was conducted using linear mixed effects models with the lme4 package in R [23]. Post-hoc analysis was performed using Tukey's HSD to adjust for multiple pairwise comparisons. We designed a model to examine the relationship between ego involvement and changes in brain activity across brain regions while considering viewing time, and the type of game event as interaction terms. For the fixed effects component of the model, we specified random intercepts for each participant. The final model specification were as follows HbO ~ Involvement*Time*Region + Involvement*Type*Region + (1|participant).

Table 2: Overview of Key Moments Analyzed During Gameplay

Event	Viewing Time (mm:ss)	Period Remaining (mm:ss)
Early		
Nottingham Chance 1	00:06	19:54
Cardiff Chance 1	02:22	18:22
Cardiff Chance 2	04:38	16:50
Nottingham Chance 2	05:43	16:09
Middle		
Cardiff Chance 3	06:22	15:30
Nottingham Chance 3	09:40	15:64
Nottingham OFO	10:12	13:02
Nottingham Chance 4	13:08	10:10
Late		
Nottingham Chance 5	14:46	08:30
Cardiff OFO	23:44	01:02
Cardiff Chance 4	24:32	00:39
Cardiff Chance 5	25:05	00:06

Results

All participants tolerated the equipment and procedure well, and usable data was obtained from all participants. For this reason, hypothesis 1 was supported. With respect to hypotheses 2 and 3, there was a significant two-way interaction between ego involvement and time $F(2, 2830) = 5.30$, $p = .005$, and a significant two-way interaction between ego involvement and region $F(3, 2830) = 3.17$, $p = .024$. *Post-hoc* comparisons were used to examine the simple effects of involvement across different time and involvement on different brain regions. Results (see **Figure 2, panel a**) indicated that across brain regions individuals with greater involvement demonstrated greater changes in HBO in response to key moments in the early portion of the game $t(82.2) = 3.13$, $p = .002$. Results (see **Figure 2, panel b**) also indicated that across time periods individuals with greater involvement demonstrated greater changes in HBO within their right dmPFC in response to key moments $t(146) = 3.24$, $p = .002$.

There was a significant three-way interaction between ego-involvement x event type x brain region $F(3, 2830) = 6.02$, $p < .001$. *Post-hoc* tests were conducted to examine the differences in HbO response across brain regions between low and high involved individuals' responses to the different types of viewing moments. Results (see **Figure 2, panel c**) indicated that the interaction was driven by significant increases in HbO for individuals with high involvement in both the left $t(215) = 2.19$, $p = .029$ and right $t(215) = 2.19$, $p = .029$ dmPFC during offensive forward opportunities.

Discussion

This proof-of-principle study aimed to examine the feasibility of fNIRS to quantify patterns of brain activation in response to in-vivo sport viewership opportunities, and to evaluate the possibility of moderating effects by ego involvement. ~~-~~It was hypothesized that fNIRS would prove feasible and provide information about the influence of both critical moments in game play, and ego involvement, as determinants of cerebral hemodynamics. We observed significant increases in oxygenated hemoglobin (HbO) in the right dmPFC of individuals with high ego involvement following key moments throughout the course of the game. Comparing the different types of events, it appears that individuals with high involvement were highly responsive to offensive faceoff opportunities as evidenced by increased HbO in both their left and right dmPFC following these moments specifically. Given the important role of the dmPFC in personally relevant social evaluations [11] the increased activation of this structure in individuals with high involvement during sports viewership experiences is theoretically meaningful.

The finding that evaluative processing within the dmPFC differed between high and low ego involved spectators across game phases provides validation of the hypothesized evaluative and self-relevance processing function of the dmPFC [12,13]. That is, it is intuitive that more value-based processing of sensory information delivered via the game play video samples would be evident among participants who were ~~emotionally~~ involved in the sport at the outset of the experiment. Beyond this, when looking at a critical game play moment (i.e., offensive face-offs), there were notably large differences in self-relevance/evaluative processing between high and low-involved spectators.

Unlike OFO, we did not detect differences in relation to SC. With respect to OFO, highly involved viewers may have been more attuned with the nuances and possibilities associated with these key moments in the game. These instances may have been a signal or cue to highly-involved spectators that something important may be about to happen—a cue that viewers with low-involvement may have been unable to evaluate. However, it may have been difficult to detect differences in SC as these critical moments may be evaluated more similarly across both involvement groups. Even those for whom the sport is not of interest or central to life may still understand the importance and relevance of a scoring chance because it is the central object (and less nuanced aspect) of the game.

There are several strengths of the current study. First, few prior studies have examined the sport viewership experience using mobile neuroimaging, and no prior studies have employed fNIRS specifically to our knowledge. From this perspective, the current findings lay the foundation for future applications of fNIRS technology in the sport viewership context and provide a demonstration of feasibility. Second, we took steps to ensure no prior exposure to experimental stimuli was likely by carefully selecting game play sequences from a familiar sport played outside of the host country for the study in question. Finally, we ensured that video stimuli contained a range of prototypical sport event moments and ensured that the viewer experience was as ecologically valid as possible.

There are also a number of important limitations worthy of mention. First, it is possible that other areas of the cortex (or less superficial levels of the brain in general), including those involved in attentional processes (such as the superior parietal lobule), may be active during specific periods of game play, but these could not be measured in the current study due to optode placement. Second, because the video clips were selected from actual game play, we cannot guarantee that there was no pre-exposure or attitudinal variation that shaped the neural responses differentially for those at different levels of involvement. Additionally, the range of events sampled in our visual stimuli was not exhaustive with respect to moments in game play, and there may be other events not captured that more fully reveal differences between those viewers who are involved versus not involved with respect to attention or evaluative processing.

Likewise, our findings are relevant in the context of ice-hockey viewership, and we caution readers in terms of their generalizability beyond this specific sport environment. Indeed, future research should attempt to understand viewership experiences using fNIRS in a variety of different sport event contexts.

Finally, while this is one of only a handful of studies to examine fNIRS in the context of sports viewership [24], at least two prior studies utilizing fNIRS to examine cortical responses to video sequences observed significant differences in prefrontal activation with comparatively modest samples [25 , 26]. These samples may be typical of fNIRS imaging studies, but there is a possibility that small samples may produce both Type 1 and Type 2 errors, depending on the circumstances, thereby contributing to unreliability of findings across studies [27] . For this reason, replication with larger samples would be warranted.

Despite these limitations, the current study is a step forward in the science of sport spectatorship experiences. Objective, continuous (i.e., ongoing throughout the viewership experience), and in situ measures of sport viewership engagement are not typically captured in previous sport consumer investigations [4]. Neuroimaging data may inform design and production elements of more engaging televised sport stimuli for diverse sets of audiences.

Conclusion

The current study examined the extent to which fNIRS is a viable technology for capturing neurocognitive aspects of the sport spectator experience in an ecologically valid manner, and the extent to which certain key moments in gameplay may be disproportionately influential. We also examined the extent to which pre-existing ego involvement with the sport viewed might moderate any such effects. Our findings largely supported our hypotheses that fNIRS would be feasible, that some key moments were more important than others, and that ego involvement predicted relatively stronger neural effects, particularly within evaluative and self-relevance processing nodes within the dmPFC. Despite limitations, the observed findings provide an initial confirmation that fNIRS is well-adapted to the sport viewership experience, and that neural signals may reliably differentiate between those who are more versus less highly involved in viewing actual game play sequences, specifically in the context of hockey. Future studies examining the reliability of such effects across different sports would be valuable, as well as experimental manipulation of cortical nodes to unpack temporal precedence and causality.

Data Availability

Data will be made available in a public data repository.

Consent for publication

Informed consent for all identifiable individuals in Figure 1 has been obtained.

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