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ABSTRACT

Individuals tend to compare themselves with others, and the results of these self-evaluations influence subsequent performance. When individuals perceive an advantage over their rivals (challenge-type response), they achieve higher levels of performance. According to the biopsychosocial model of challenge and threat, benefits of favourable appraisals are partly mediated by cardiovascular efficiency, which is increased by challenge and decreased by threat evaluations. In this study, we tested whether the biopsychosocial model can be extended to predict behavioural outcomes in esports. We expected that challenge-type evaluations would increase performance compared to threat-type evaluations. Eighty-two men were assigned to a challenge or threat group and completed three rounds of Counter-Strike: Global Offensive – a video game popular in esports. Individuals with the highest scores were awarded cash prizes. Cardiovascular markers of challenge and threat, cognitive appraisals, and game scores were recorded. We manipulated the social challenge and social threat evaluation by informing participants that their performance in the initial round was superior (challenge) or inferior (threat) compared with other gamers. We found that individuals with more gaming experience, believed they were better than other gamers, had higher heart rate and, in turn, achieved higher scores. These effects were related to initial situational appraisal at the baseline and were not boosted by feedback provided during the actual performance. These results are the first to document that social comparisons among gamers are accurate in the prediction of future physiological and behavioural outcomes. Furthermore, these findings emphasize that physiological responses mediate relationships between action-related cognitions and performance.

1. Introduction

Thinking about other people in relation to the self is a core process in human social information processing (Festinger, 1954; Mussweiler, 2003). While comparing, individuals seek similarities and differences to adjust their self-evaluations, affect, and behaviour. In upward comparisons, the comparison standard (e.g., another competitor) is better off than the comparer. In downward comparisons, people focus on individuals with fewer resources, e.g., competitors with lower skills. Social comparisons influence individuals' emotions and well-being (Jordan et al., 2011), self-esteem (Vogel, Rose, Roberts, & Eckles, 2014), performance outcomes (Christy & Fox, 2014), and performance satisfaction (Gächter & Thöni, 2010).

Comparing with others is particularly important when people compete with each other in pursuit of the same valuable goal. When people see that they have an advantage over others a challenge response is initiated that engages cognitive (challenge evaluation), physiological (e.g., cardiovascular), and behavioral systems (e.g., motor system) (Blascovich, 2008). Individuals who perceive their advantage over others are motivated to invest resources because this effort is likely to generate a profit. Consequently, challenged individuals are more likely to succeed (Mendes, Blascovich, Major, & Seery, 2001; Scheepers, de Wit, Ellemers, & Sassenberg, 2012). In contrast, when people see that they are less resourceful, a threat response is initiated, which is oriented towards the minimization of losses and unnecessary expenditure of resources. Individuals who perceive their disadvantage over others can withdraw to avoid the unprofitable investment of resources (Blascovich, 2008). Thus, the level of performance is decreased. Of the processes that explain the link between action-oriented self-cognitions and behavioral outcomes, cardiovascular functions has received considerable attention resulting in the formulation of the biopsychosocial model of challenge and threat (Blascovich, 2008; Seery, 2011; Seery, 2013). Above all, the facilitative effect of challenge on performance has been partially explained by increased cardiac efficiency observed during performance of challenged individuals (Behnke & Kaczmarek, 2018).

Several studies have documented how evaluating the situation as a challenge or threat influence performance (e.g., Moore, Vine, Wilson, & Freeman, 2012; Turner et al., 2013). However, a recent meta-analysis revealed weaknesses in the challenge–threat literature (Blascovich, 2008; Seery, 2013), such as reduced support for the biopsychosocial model from experimental evidence where the levels of challenge and threat were manipulated (Behnke & Kaczmarek, 2018). This is important because experiments provide the most powerful design for testing causal hypotheses (Chambliss & Schutt, 2018). Causality inferences are justified when there is an empirical association between

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variables, the temporal priority of the independent variable, and the risk of spurious effects is minimized. Understanding causality informs how to develop efficient interventions that improve performance (Michie, Van Stralen, & West, 2011).

Moreover, few studies in the biopsychosocial model literature have accounted for situations where research participants performed activities central to their interests, e.g., initiated in their leisure time (Moore, Vine, Wilson, & Freeman, 2014; Vine et al., 2015). Studying self-selected individuals is essential because it provides high motivational context, which is necessary for the challenge and threat effects to occur (Blascovich, 2008). High level of task-related motivation is important because individuals must recognize a valuable goal before they take the effort of evaluating whether they have sufficient resources to achieve this goal (challenge) or whether they have deficits in resources and the goal is unlikely to be achieved (threat). Without a meaningful and stimulating goal, neither challenge nor threat occurs (Seery, 2013).

Finally, previous studies on the biopsychosocial model examined how pre-performance physiological changes affect performance rather than physiological function during the actual performance. Noteworthy, some authors have addressed the need to account for challenge and threat physiological processes during the performance (Arthur, Wilson, Moore, Wylie, & Vine, 2019). For instance, previous studies indicated robust links between task engagement and physiological function during performance (De Manzano, Theorell, Harmat, & Ullén, 2010; Nakahara, Furuya, Obata, Masuko, & Kinoshita, 2009). Moreover, research documented that intense physical activity does not obscure the psychological effects on physical responses (Nakahara et al., 2009).

To address these limitations, we aimed to examine challenge and threat cognitive and physiological responses in a novel behavioral context of esports performance. Esports is a novel development in the field of sports where gamers compete using video games (Hamari & Sjöblom, 2016). Competitive video gaming allows studying physiological responses with relatively little interference from the onset of motoric activity. Thus, we organized an esports tournament to account for the effects of social comparisons among gamers.

1.1. Challenge and threat states

Individuals that are motivated to achieve a goal estimate their current resources which are necessary to succeed (e.g., skills, knowledge, and abilities) relative to situational demands (e.g., danger, uncertainty, and required effort) (Lazarus & Folkman, 1984). According to the biopsychosocial model of challenge and threat, when individuals evaluate their resources as sufficient to overcome the situational demands, they experience the challenge state (Blascovich, 2008). On the other hand, threat state appears when situational demands exceed individuals' resources (Blascovich, 2008). Challenge and threat evaluations are two opposing evaluations that reflect the abundance vs. the shortage of resources. Several factors determine resources/demands evaluations during the performance, including changes in task difficulty (Fonseca, Blascovich, & Garcia-Marques, 2014), win and lose possibilities (Seery, Weisbuch, & Blascovich, 2009), self-esteem (Seery, Blascovich, Weisbuch, & Vick, 2004), or goal-setting: e.g., performance-approach vs. performance-avoidance goal (Chalabaev, Major, Cury, & Sarrazin, 2009). When two individuals compete with each other in the sporting context, situational demands relate to opponent skills.

Challenge and threat evaluations lead to a cascade of physiological responses (Blascovich, 2008; Seery, 2011). Four measures of cardiovascular reactivity were used within the challenge and threat paradigm: heart rate (HR), pre-ejection period (PEP; time in milliseconds in the cardiac cycle from initiation of ventricular depolarization to opening of the aortic valve and ejection of blood), cardiac output (CO; the amount of blood in litres pumped by the heart per minute), and total peripheral resistance (TPR; an index of net constriction vs dilation in the arterial system; Blascovich, 2008). During the performance, individuals are motivated to engage their physiological resources necessary for action (Mendes & Park, 2014). This results in increased sympathetic activation in the autonomous nervous system, observed in increased HR and shortened PEP (Seery, 2011). Thus, higher HR and PEP reactivity are interpreted as indicative of stronger motivational intensity. This initial physiological response is further modulated by individuals resources/demands evaluations that initiated cardiovascular challenge and threat response. Cardiovascular challenge response is characterized by activation of the sympathetic-adrenal medullary system, which leads to the release of adrenaline into the bloodstream. Consequently, vasodilatation occurs (widening of blood vessels), which along with higher HR, results in increased CO and decreased TPR (Brownley, Hurwitz, & Schneiderman, 2000). In contrast, threat evaluation inhibits the release of adrenaline and instead releases cortisol that leads to vasoconstriction (narrowing of blood vessels). It produces less efficient blood flow characterized by little or no change in CO and an increase in TPR (Seery, 2011).

The challenge and threat framework has become one of the leading theoretical models for psychophysiological responses related to motivated performance (Blascovich, Seery, Mugridge, Norris, & Weisbuch, 2004; Seery et al., 2009; Turner, Jones, Sheffield, & Cross, 2012). The facilitating effects of experiencing challenge rather than threat have been demonstrated in several areas, including learning new skills (Moore et al., 2014), solving cognitive tasks (Scheepers, 2009), negotiating prices (Scheepers et al., 2012), or practicing sports, e.g., playing golf (Moore et al., 2012). A recent meta-analysis supported the facilitative role of the challenge type cardiovascular response linking it with superior performance results (Behnke & Kaczmarek, 2018).

1.2. Esports

Esports is a form of competition that uses video games (Bányai, Griffiths, Király, & Demetrovics, 2019; Hamari & Sjöblom, 2016; Trotman, Williams, Quinton, & van Zanten, 2018). For instance, gamers compete in esports with each other by controlling avatars in a video game world. Esports is a recent development in the field of sports. In order to be considered sports, an activity must meet following criteria: 1) include play (voluntary, intrinsically motivated activity), 2) be organized (governed by rules), 3) include competition, 4) be comprised of skills (not chance), 5) include physical skills—skilful and strategic use of one's body, 6) have a broad audience, and 7) have achieved institutional stability where social institutions have rules which regulate it and stabilize as an important social practice (Gutmann, 2004; Jenny, Manning, Keiper, & Olrich, 2017; Suits, 2007). Esports meets all of the criteria (Jenny et al., 2017; Jonasson & Thiborg, 2010).

Esports is a relatively new social phenomenon with increasing popularity reflected in regular professional leagues (i.e., Electronic Sports League) and tournaments (i.e., Intel Extreme Masters, World Champions, The International). The events are organized by the international esports federations (i.e., International Esports Federation, IeSF) and are watched by hundreds of millions of viewers (Esports Charts, 2019; Hutchins, 2008; Wagner, 2006). People practicing esports are called gamers or pro-gamers in the case of professionals (Taylor, 2012). The average gamer is between 15 and 25 years old and practices approximately 20 h per week (Müller-Lietzkow, 2006). Competitive video gaming involves psychological processes that are characteristic of other sports disciplines, such as quick and accurate decision-making, focused attention, emotion regulation, and extensive game knowledge (Hilvoorde & Pot, 2016; Himmelstein, Liu, & Shapiro, 2017; Ravaja, Saari, Salminen, Laarni, & Kallinen, 2006). Additionally, due to its competitive environment, esports also involves highly motivated individuals (Przybylski, Ryan, & Rigby, 2009). However, there are also meaningful differences in esports performance compared with real-world competitions that are of particular interest to social psychophysiology.

First, during esports, gamers perform in a seated position with most of the physical activity executed in the digital world of the game. It raises a unique situation, where psychophysiological processes can be observed with relatively little interference from the onset of motoric activity. This allows checking whether the conclusions concerning the pre-performance period may be extended to the actual competition. Second, the use of computers and video games allows for the testing of individuals in carefully controlled and manipulated conditions. For instance, gamers can compete against computer-controlled avatars which provide fully standardized and replicable testing conditions – a situation that is not likely to occur in real-world competitions. In summary, research on esports allows testing integrative, multilayer models that account for the role of psychological factors in the course of performance. However, only a few studies have been carried out on esports performance (e.g., Drachen et al., 2014; Rambusch, Jakobsson, & Pargman, 2007; Ravaja, Turpeinen, Saari, Puttonen, & Keltikangas-Järvinen, 2008; Trotman et al., 2018).

1.3. Present study

We aimed to adopt a novel esports research design to examine how social challenge and threat influence gaming outcomes and whether psychophysiological factors may explain these effects. Based on the biopsychosocial model of challenge and threat (Blascovich, 2008), we predicted that a challenge-type evaluation (participants reporting high personal resources relative to situational demands) would be related to superior performance (game score) compared to threat-type evaluation (participants reporting low personal resources relative to situational demands). We expected that individuals who are more challenged during the competition would be more successful later compared with threatened individuals. Finally, we expected that the effects of the challenge and threat evaluation on behaviour (game score) would be mediated by increases in CO, a physiological onset of challenge and threat evaluation indicative of increased cardiovascular efficiency (increased blood flow through the body) (Seery, 2011). We controlled for HR and PEP as physiological indexes of task engagement mediated by sympathetic activation (increased HR and shorter PEP) or parasympathetic withdrawal (increased HR). We organized an esports tournament, that served as a motivated performance context that would attract motivated gamers. The biopsychosocial model of challenge and threat assumes that challenge/threat evaluation occurs when an individual is motivated to perform well (Blascovich, 2008). Thus, we aimed to motivate participants to their peak performance by providing an additional incentive, i.e., prize money in a tournament. Furthermore, by organizing a tournament we provided an ecologically valid context representative for sports activity rather than casual leisure time gaming.

2. Method

2.1. Participants

Participants were 82 *Counter-Strike: Global Offensive* (*CS: GO;* Valve Corp., USA) gamers between the ages of 18 and 31 years ($M = 19.47$, $SD = 2.48$). A power analysis using G*Power 3.1 (Faul, Erdfelder, Buchner, & Lang, 2009) indicated that a sample size of 82 participants allowed the detection of moderate effect sizes of $f = 0.15$ for multiple linear regression with up to two predictors and power of .80. We recruited gamers via a Facebook advertisement targeted at *CS: GO* gamers. Of the participants, 72 (88%) were recreational gamers, 7 (8%) were non-professional esports gamers (competing in local or online tournaments), and three (4%) gamers did not report their status. Participants played *CS: GO* systematically, playing form 1 h to 40 h 15.72 h per week on average ($SD = 8.53$). Gamers had normal or corrected vision and no known family history of cardiovascular or respiratory disease. Participants were asked to reschedule if they experienced illness or a significant adverse life event. We asked participants to refrain from vigorous exercise, food, and caffeine for 2 h before testing. We introduced the above restrictions to eliminate factors that might affect cardiovascular functions or usual gaming performance examined in this study. Participants were tested individually and received a voucher for a cinema ticket for participation in the study. To increase the motivation to participate in the study, we announced cash prizes for the top three gamers ($60, $30, and $15 respectively). Top gamers received their prizes once the research has been completed. Each participant provided written informed consent. The institutional ethics committee approved the study.

2.2. Measures

2.2.1. Physiological measures

Cardiovascular challenge and threat response. Responses on the cardiovascular challenge – threat dimension were operationalized as responses in HR and PEP followed by responses in CO. Increased HR reflects sympathetic activation and parasympathetic withdrawal in the autonomous nervous system (Blascovich, Vanman, Mendes, & Dickerson, 2011). Shorter PEP reflects sympathetic activation. These responses (increased HR and shorter PEP) are characteristic of physiological readiness to a motivated performance (Blascovich, 2008). Resources/demands evaluations lead to changes in CO that reflect the volume of blood being pumped by the heart per minute. Challenge response is characterized by increased CO, and threat response is characterized by decreased CO (Blascovich, 2008; Seery, 2011). Challenge and threat cardiovascular response is also reflected in changes in total peripheral resistance (TPR) that indicates resistance that must be overcome to push blood through the circulatory system. CO and TPR are highly inversely correlated (Seery, Weisbuch, Hetenyi, & Blascovich, 2010). We were not able to calculate TPR because we did not measure blood pressure while participants used both hands to control the keyboard and mouse intensely during the game.

Cardiovascular biosignals were recorded continuously and non-invasively with the Vrije Universiteit Ambulatory Monitoring System (VU-AMS, the Netherlands) following psychophysiological guidelines (Sherwood et al., 1990). Impedance cardiography (ICG) and electrocardiography (ECG) recordings provided continuous measures of cardiac action and hemodynamic levels. The VU-AMS recorded ECG pre-gelled AgCl electrodes (Kendall Abro, H98SG) placed in a Lead II configuration (on the right collar bone and left side of the chest). Impedance cardiography was recorded with pre-gelled AgCl electrodes (Kendall Abro, H98SG) with a four-spot electrode array (Houtveen, Groot, & De Geus, 2005; Sherwood et al., 1990). The first electrode was placed over the sternum between the two collarbones, the second over the tip of the xiphoid complex of the sternum, the third on the back over cervical vertebra C4, and the fourth between thorax vertebras T8 and T9. Based on ICG and ECG signals, we calculated HR, PEP, and CO. After the VU-AMS Data, Analysis & Management Software (VU-DAMS 3.0) detected R-peaks in the ECG, we visually checked and adjusted all R-peak markers when necessary. We scored CO and PEP from 30-s ensemble averages of the ICG using the validated VU-AMS interactive scoring software (Kupper, Willemsen, Boomsma, & De Geus, 2006). Scoring was performed blind to other participant data. We used averaged measures from the Match1 and Match 2 period. Next, we calculated reactivity scores for HR, PEP, and CO (Christenfeld, Glynn, & Gerin, 2000), where the score of the last 2 min of baseline was subtracted from the Match 1 and Match 2. This calculation is mathematically equivalent to computing the area between the reactivity curve and the resting level. Using difference scores is a standard strategy for the study of autonomic responses to psychological factors (e.g., Monfort et al., 2014).

2.2.2. Performance

Participants played *Counter Strike: Global Offensive* (*CS: GO)*, which is a multiplayer team-based first-person shooter where two teams compete against each other in simulated military combat. *CS: GO* is the leading game in the esports team-play category. It is also a popular leisure activity that engages up to 600,000 daily active gamers worldwide (Steam & Game stats, 2019). In this game, individuals from two teams with opposing motives: counter-terrorists vs. terrorists. The mission of the counter-terrorists is to disarm explosives planted by the terrorists or eliminate all member of the opposing team. Players are eliminated from the match when their avatars suffer fatal damages received from other gamers. In *CS: GO*, gamers compete online against other gamers or offline against computer-controlled characters.

To standardize conditions across participants, each participant competed in a deathmatch mode on the Dust II map against computer-controlled avatars (bots) set at the maximum difficulty level (expert). The game system calculated each match score by multiplying the points for eliminating each enemy bot by the weapon difficulty level. Higher scores indicated better performance. To determine whether these settings were sensitive to psychological influences, we calculated correlation of scores between Match 1 and Match 2 as a measure of testing reliability and the coefficient of variation, i.e., ratio of the standard deviation to the mean (Currell & Jeukendrup, 2008). The coefficient of variation was acceptable for both matches, 21% for Match 1 and 19% for Match 2. Moreover, a strong correlation between scores in Match 1 and Match 2, $r = 0.56$, $p < .05$, indicated that the gaming outcomes were not due to chance and reflected individual gaming skills and efforts.

2.2.3. Challenge and threat evaluation

We used a validated approach to the measurement of challenge and threat evaluations conceptualized as the difference in resources (action-oriented self-evaluation) and demands (evaluation of others) (Seery, 2011; Tomaka, Blascovich, Kelsey, & Leitten, 1993). We asked participants how they rated their level of *CS: GO* skills and what they thought about the skills of other participants in the contest. Participants used a 7-point scale ranging from 1 (‘extremely low skills’) to 7 (‘extremely high skills’). After subtracting demands for winning the competition (other gamers’ skill levels) from resources (own skill level), the evaluation score ranged from −6 to +6 with positive scores reflecting high social challenge and negative scores reflecting high social threat.

2.2.4. Gaming experience

CS: GO gaming experience was conceptualized as the total time spent playing the game. Gamers were asked to report total hours played that was counted by the gaming system (Steam Library; Valve Corp., USA). Gamers reported CS: GO gaming experience from 75 to 3900 h ($M = 1008$ h, $SD = 556.67$) (Steam Library; Valve Corp., USA).

2.3. Challenge and threat manipulation

Participants were randomly assigned to the social challenge or the social threat group. We manipulated challenge and threat evaluations through fake feedback that we provided to the participants. The instructions were adapted from previous research (e.g., Feinberg & Aiello, 2010; Moore et al., 2012). For example, the challenge instructions facilitated downward social comparison; i.e., we informed participants that they performed better than 83% of other gamers. To maintain task engagement, both groups received instructions emphasizing the importance of Match 2 of the tournament and we also prompted rewards for the highest-scoring participants.

> You have just finished the first round of the tournament. Your score is [the real score was displayed here]. You achieved a result higher than 83% of the tournament participants. Now, the second round will take place. This is the most important part of the study, so we ask you to do your best and improve your score from the previous round. The top three performers will be awarded cash prizes of $60, $25, and $15, respectively. Think of the upcoming round as a challenge to be met and overcome. Research has shown that the best gamers improve their scores in final rounds. Think of yourself as someone capable of meeting that challenge and do your very best. With these instructions and the belief that you are able to win the tournament in mind, please wait for the second round.

For the threat elicitation, we used the following instruction:

> You have just finished the first round of the competition. Your score is [the real score was displayed here]. You achieved a result lower than 83% of the tournament participants. Now, the second round will take place. This is the most important part of the study, so we ask you to do your best and improve your score from the previous round. The upcoming round can be a difficult and frustrating task, and you may not improve your scores from the first round. Research has shown that most gamers do not improve their scores in final rounds. Although the task may seem difficult, try your best. With these instructions in mind, please wait for the second round.

2.4. Procedure

Participants were tested individually in a sound-attenuated and air-conditioned room. Upon arrival in the lab, participants provided informed consent, and the researcher applied sensors to obtain cardiovascular measurements. After the experimenter left the testing room, participants received instructions and responded via a PC with a 23-inch screen located in their cubicle. Participants reported demographics and sat quietly for the next 5 min.

Participants were given 10 min for free play as a warm-up (Fig. 1). They reported how they perceived the upcoming match regarding demands and resources (challenge and threat status). After 2 min of resting, they completed the first round of the esports competition (10 min) and received fake feedback regarding their inferior or superior performances relative to other competitors. They re-evaluated their resources, rested for 2 min, and completed the second round of the competition. Upon completion, participants were debriefed and received cinema vouchers for their participation. A few weeks later, the tournament winners received their awards.

2.5. Analytical strategy

2.5.1. Preliminary analyses

Before testing hypotheses, we checked the validity of the study procedure (did the performance produce meaningful HR response indicative of motivational intensity), and the experimental manipulation (did the performance feedback produce changes in the challenge and threat evaluation).

Motivated performance. First, we tested whether gamers attending esports competition were physiologically engaged to recognize this situation as motivated performance. As an indicator of behavioural motivation intensity and action readiness, we tested whether individuals increased their HR levels (Moore et al., 2014). For this purpose, we used a repeated measures analysis of variance (ANOVA). We tested whether participants increased from main baseline to pre-match baseline in HR and PEP.

Participants self-selected to participate in the tournament. Thus, we expected they might already be highly motivated and aroused at the baseline, and further increase their motivation and arousal during the competition. Most performers tend to increase their HR before the performance as indicated by research among bikers (Mateo, Blasco-Lafarga, Martínez-Navarro, Guzmán, & Zabala, 2012), swimmers (Cervantes Blásquez, Rodas-Font, & Capdevila Ortís, 2009), or musicians (Abel & Larkin, 1990). Therefore, we tested absolute HR levels at pre-match baseline against the normative resting HR of 64.80 beats per minute reported in a meta-analysis (Nunan, Sandercock, & Brodie, 2010). We reported the effect size of this difference using Cohen’s *d*.

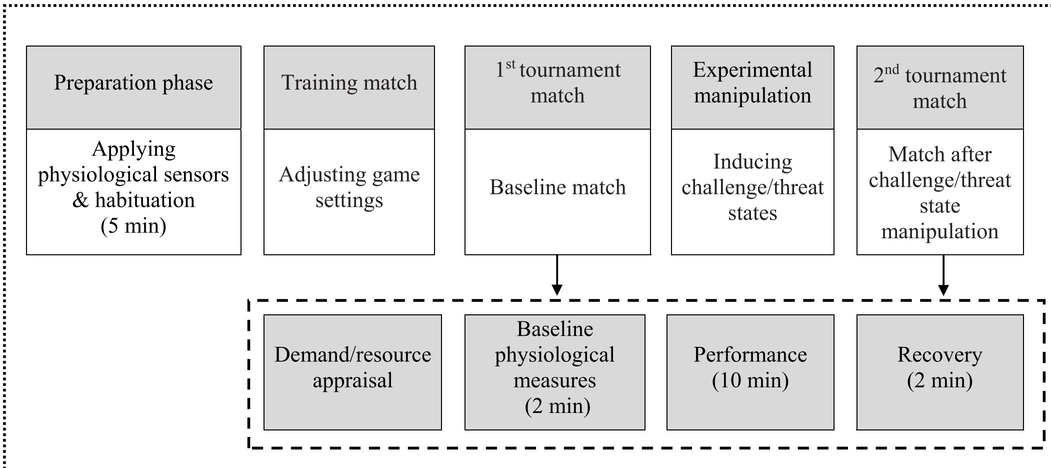

Fig. 1. Study procedure.
Note. Dotted frame represent study procedure, dashed frame represent repeated procedure of tournament matches.

Table 1
Correlation matrix and descriptive statistics.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1. Score T1										
2. Score T2	.56**									
3. Evaluation T1	.32**	.21								
4. Evaluation T2	.30**	.19	.32**							
5. CO T1	.02	-.02	.11	-.13						
6. CO T2	.15	.12	.14	-.06	.79**					
7. HR T1	.34**	.19	.40**	.22*	.40**	.35**				
8. HR T2	.23*	.19	.36**	.25*	.32**	.37**	.88**			
9. PEP T1	-.05	.02	-.12	-.05	-.38**	-.26*	-.37**	-.24*		
10. PEP T2	.12	.14	-.11	.13	.00	.01	-.18	-.13	.43**	
11. Group	.10	.05	.37**	−0.07	−0.07	−0.01	0.08	0.01	0.11	−0.19
M	459.16	477.87	−0.57	−0.49	−0.60	−1.15	0.01	−0.06	−2.83	−1.60
SD	96.51	90.21	1.52	2.09	2.65	2.75	6.31	7.34	11.54	13.33

$^*p < .05$. $^{**}p < .01$.
Note. Descriptive statistics present change scores relative to baseline. Group coded as threat = 0, challenge = 1. T1 and T2 = measurement for match 1 and match 2, Evaluation = cognitive appraisal of resources vs situational demands. CO = cardiac output, HR = heart rate, PEP = pre-ejection period.

Manipulation check. To support the effectiveness of experimental manipulation, we tested whether there was an interaction between feedback (superior vs. inferior results) and time (pre-test vs. post-test) in their effect on the challenge and threat evaluation. We expected that individuals would experience increases in challenge and threat evaluation after receiving feedback about their superior performance and decreases after receiving feedback about their inferior performance.

2.5.2. Main analysis

We tested how the challenge and threat evaluations affect the performance outcomes and physiological responses during the gameplay. Main hypotheses were tested using a path analytical approach with maximum likelihood mean, and variance adjusted estimator (MLM) performed using mPlus 7.2 (Muthen & Muthen, 2012). This technique allows the testing of specific direct and indirect pathways between experimental factors, moderators, and outcomes. The number of participants was acceptable for small sample size path analysis (Bentler, 2007). The hypotheses can be considered supported if the model fits the data well – i.e., RMSEA < 0.06, CFI > 0.95, and SRMR < 0.08 (Hu & Bentler, 1999) – and the regression coefficients for hypothesized direct and indirect effects are significant.

3. Results

3.1. Preliminary analysis

Motivated performance. We compared absolute levels of HR during baseline ($M = 87.62$, $SD = 11.87$) and before Match 1 ($M = 87.47$ $SD = 11.02$). A repeated measures ANOVA showed that participants did not further increase their HR between baseline and before Match 1, $F(1, 81) = 0.09$, $p = .77$, $\eta^2 = 0.001$. Participants did not decrease their PEP either, $F(1, 81) = 2.41$, $p = .12$, $\eta^2 = 0.03$, when comparing their baseline ($M = 105.55$, $SD = 17.27$) with pre-game levels in Match 1 ($M = 104.15$ $SD = 16.46$). However, gamers displayed higher absolute HR at baseline when compared to normative resting HR ($M = 64.80$, $SD = 6.67$), t $(81) = 17.40$, $p < .01$, $d = 3.40$ (Nunan et al., 2010).

Manipulation check. Supporting the validity of experimental manipulation, we found a significant interaction between the experimental condition and time in their effect on challenge and threat evaluation, F $(1, 81) = 22.47$, $p < .01$, $\eta^2 = 0.22$. After receiving positive feedback, the challenge and threat evaluation significantly increased, F $(1, 40) = 9.89$, $p < .01$, $\eta^2 = 0.21$, and after negative feedback, the evaluation significantly decreased F $(1, 40) = 12.87$, $p < .01$, $\eta^2 = 0.25$.

3.2. Main analysis

Descriptive statistics and correlations between study variables are

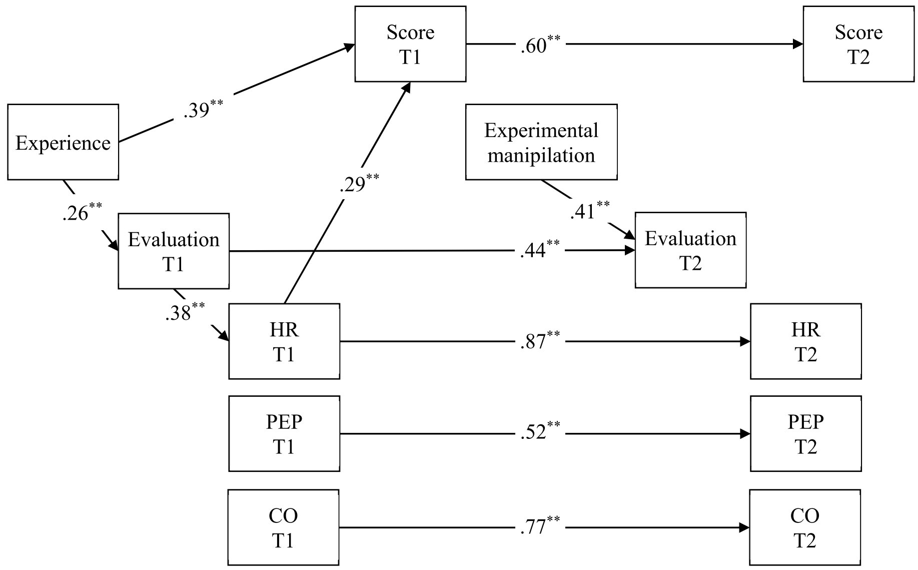

Fig. 2. Final model
Note. T1 and T2 = measurement for match 1 and match 2; Evaluation = cognitive appraisal of resources vs. situational demands. HR = heart rate, CO = cardiac output, PEP = pre-ejection period, Score = game results.

presented in Table 1. The final model fit the data well, χ^2 (42) = 51.75, p = .14, RMSEA = 0.06, 90% CI [0.00, 0.12], SRMR = 0.08, CFI = 0.97 (Fig. 2). Non-significant paths had no effect on the model fit, $\Delta\chi^2$ (2) = 3.99, p > .05; thus, they were removed.

As expected, more experienced gamers evaluated the game as more challenging and scored higher in Match 1 and Match 2; a significant indirect effect via the Match 1 score, β = 0.23, p < .01 (Fig. 2). Moreover, participants who perceived the upcoming game as a challenge (resources outweigh situational demands) displayed higher HR reactivity compared to individuals who perceived the upcoming game as a threat (situational demands outweigh resources). Thus, higher HR reactivity was also related to higher game scores. We observed an indirect effect of experience on game scores during Match 1 via challenge and threat evaluation and HR, β = 0.03, p = .04. HR reactivity during Match 1 had a direct effect on higher scores and an indirect effect on higher scores in Match 2 via scores in Match 1, β = 0.14, p = .03. Challenge evaluation before Match 1 had an indirect effect on higher scores in Match 1 via increased HR, β = 0.11, p = .02, and in Match 2 via HR reactivity and scores in Match 1, β = 0.06, p = .04.

Individuals who received performance-related superiority feedback felt more challenge during Match 2 compared with individuals who were informed that their performance was worse than that of the majority of contestants. However, this feedback had no consequences for performance and physiological processes. Performance and physiological processes during Match 2 were largely predicted by their initial levels, i.e., auto-regression. CO, as the expected challenge and threat state indicator, was not related to evaluations and game scores. PEP did not correlate with model variables. Finally, pre-performance physiological levels were not predictive in the model.

4. Discussion

In this study, we aimed to examine whether challenge and threat evaluation influenced gamers' performance and whether challenge and threat evaluation was influenced by the provision of situational performance-related feedback. Moreover, we examined whether the influence of cognition on behavioural outcomes was mediated by physiological processes that indicate motivational intensity and challenge and threat cardiovascular response.

The main finding in this study is that individuals who had more gaming experience initially perceived the abundance of personal resources (their skills) relative to demands to win the contest (other gamers' skills) and, in turn, were more successful than individuals who perceived their initial resources as insufficient relative to demands. This relationship occurred for challenge and threat appraisals in Match 1, and indirectly in Match 2. Moreover, challenged individuals mobilized greater physiological resources, as indexed by higher HR, but did not achieve greater cardiac efficiency, as indexed by CO. This might mean that the heart action was faster but the amount of blood circulating in the CV system remained the same. Because CO is the product of HR and stroke volume (the amount of blood ejected from ventricles due to each contraction) (Blascovich et al., 2011), increased HR with no changes in CO suggests that there might have been decreases in stroke volume. Alternatively, increased HR could result from decreased blood pressure via baroreflex response (Heesch, 1999). A broader interpretative framework would be possible if blood pressure measures were available. However, it was not feasible to measure blood pressure in the current setup due to the amount of hand movement in gamers.

We found support for the role of challenge and threat evaluation in predicting desirable outcomes (Gildea, Schneider, & Shebilske, 2007). Although the critical role of favourable self-evaluations in goal-oriented behaviour has been documented in previous theories and studies (e.g., Feinberg & Aiello, 2010; Lazarus & Folkman, 1984; Putwain, Symes, & Wilkinson, 2017), we extended the generalizability of this model to competitive video gaming. The replicative part of this research is essential because several analyses indicate that effects reported in the psychological literature often fail to replicate (Camerer et al., 2018; Open Science Collaboration, 2012; 2015).

We also accounted for physiological responses that complemented and partially explained the link between challenge and threat evaluations and behaviours. In comparison to the approach that examined pre-performance physiological responses, we accounted for changes occurring during the actual performance (e.g., Chalabaev et al., 2009; Ell, Cosley, & McCoy, 2011; Frings, Eskisan, Spada, & Albery, 2015; Mendes, Blascovich, Lickel, & Hunter, 2002; Scholl, Moeller, Scheepers, Nuerk, & Sassenberg, 2017). We observed that more challenged individuals had higher HR, which is suggestive of stronger mobilization of physiological resources (Seery, 2013). Pre-match cognitions and HR activity during the performance were related to higher subsequent scores throughout the whole tournament. Taken together, these findings indicated that the benefits of positive game-related cognitions initiate bodily responses that help achieve higher scores. Moreover, we failed to replicate the pre-performance physiological levels in the prediction of performance outcomes. This might suggest that meaningful cardiovascular influences started or reached significant levels in the performance phase of the study. Thus, challenge and threat response influenced physiological levels during the game rather than while anticipating. Previous studies also indicated that higher HR during performance reflects high task engagement (De Manzano et al., 2010), active rather than passive involvement in activity (Nakahara et al., 2009), or performing rather than rehearsing (Iñesta, Terrados, García, & Pérez, 2008). We believe that this approach contributes to the biopsychosocial model literature by indicating that the physiological levels during performance convey significant information that is related to behavioral outcomes.

Noteworthy, we observed that gamers in this study had higher levels of HR than usual resting levels while anticipating the performance (baseline). One explanation of this effects is that gamers attending our esports event might have been already physiologically aroused and motivated at the baseline, presumably due to the anticipation of the competition. This might indicate that gamers achieved high motivational intensity and physiological engagement before the game and did not further increase throughout the game. Similar findings were observed in previous studies where bikers, swimmers, and instrumentalists displayed increased HR before the performance (Abel & Larkin, 1990; Cervantes Blásquez, Rodas Font, & Capdevila Ortís, 2009; Mateo et al., 2012). There are several reasons why it might be adaptive to be fully physiologically mobilized before the competition rather than initializing mobilization after the competition starts. First, early physiological mobilization is likely to provide immediate availability of physiological resources during the performance (Mendes & Park, 2014). Second, early physiological mobilization (e.g., increased HR) provides more time for arousal reappraisal (Jamieson, Crum, Goyer, Marott, & Akinola, 2018). Individuals have more time to adjust to their arousal before the necessity to allocate their attention to the task rather than changes in the body.

Contrary to expectations, we did not observe CO levels measured before or during the performance as being predictive of better scores. This means that increased blood flow throughout the body resulting from vasodilatation did not facilitate gaming outcomes. This contradicts the biopsychosocial model (Blascovich, 2008) as well as other research that indicated that increased CO facilitates better performance (e.g., Moore et al., 2014; Scholl, et al., 2017; Turner et al., 2013). One explanation of this null effect might pertain to the behavioural specificity of gaming (based on precision movements rather than gross body movements) compared with other forms of behavioural activity that were used to test the biopsychosocial model. However, a meta-analysis revealed that previous studies provided support that CO is equally predictive of successful activity which requires gross body movements (e.g., running) and precision movements (e.g., darts) (Behnke & Kaczmarek, 2018). Some authors emphasize that although the challenge cardiovascular response is usually accompanied by better performance (Blascovich, Mendes, Hunter, Lickel, & Kowai-Bell, 2001), the relationship between challenge CV markers and outcomes can be sometimes related indirectly via psychological mediators such as effort (Scheepers, 2009). Thus, it is not unlikely that other components of the psychophysiological mechanism among *CS: GO* gamers were needed to reconstruct the path between CO and behavioral outcomes. Another explanation might be that *CS: GO* gaming is based on quick planning and decision-making: a type of cognitive activity that is sparsely represented in the biopsychosocial literature. There have been two studies that also found that CO was not predictive of performance levels where participants played golf (Moore et al., 2012) or performed a word-finding task (Scheepers, 2009). Thus, a growing number of studies suggest that there might be some unaccounted moderators for the relationship between CO and behavioural outcomes.

Moreover, the positive feedback had a large facilitating effect, and the negative feedback had a large detrimental effect on the challenge and threat evaluation; yet, this feedback did not further influence physiological responses or performance outcomes. We observed that gamers who received bogus feedback informing them about their advantage over other gamers reported increased resources in comparison to the situation requirements. In contrast, gamers who were informed that they were worse than the majority of other gamers felt more threatened. This indicates that challenge and threat evaluations are sensitive to situational feedback among *CS: GO* gamers. Previous studies also reported the malleability of the stress evaluation (Putwain et al., 2017). In this study, we addressed a social challenge and threat, conceptualized as a situation when winning or losing depends on the performance of other people. This links the current research to the social comparisons literature because social challenge and threat are special cases of challenge and threat evaluations (Gerber, Wheeler, & Suls, 2018). We found that a critical aspect of gamers' performance was easily manipulated by providing upward and downward comparisons. Although we found effects of spontaneous but not manipulated evaluation, some other studies indicated that individuals reap other psychological benefits (e.g., self-esteem) when they contrast themselves with others (Mendes et al., 2001). Above all, encouraging downward social comparisons might be especially facilitative in some circumstances because individuals do not tend to form spontaneous downward social comparisons, even when they feel threatened (Gerber et al., 2018). In contrast, individuals tend to form upward social comparisons – a strategy that may worsen their performance. Hence, this study adds to accumulating evidence that social comparisons are vital for performance regulation (Gerber et al., 2018). Yet, these effects may pertain mostly to initial assessments (primary evaluation) rather than assessments modified in the course of performance: i.e., reappraisal (Lazarus & Folkman, 1984).

This study has practical implications. First, this study suggests that video gamers are less likely to succeed when they maintain inferior social beliefs. We presented that strong beliefs in own skills before the competition may lead to successful performance. This indicates that gamers tend to be accurate at determining their performance level relative to other gamers. Experienced gamers accurately predicted that they would do well and further feedback did not influence their outcomes. This seems to suggest that it is important to develop self-confidence during the training and pre-competition phase as a component of an overall resilience building. For instance, coaches might plan the season schedule to help their athletes to build stronger self-confidence as a distinct component of mental training (Behnke, Tomczak, Kaczmarek, Komar, & Gracz, 2019). Consequently, athletes might be more resistant to misleading threatening information during competitions, i.e., inferiority feedback from the opposing team or fake news related to rivals' excellent shape. It is, however, worth noting that this observation is based on differences in a primary evaluation that was not subject to manipulation and is not based on causal effects. Thus, it is difficult to distinguish to which extent the primary evaluation reflects psychological processes rather than actual differences in skills that individuals might possess based on their previous gaming experience and previous social comparisons. For instance, it would be possible to distinguish between primary situational evaluation and actual differences in gaming experience, if we selected individuals with no experience in multiplayer first-person shooter video games and randomized them into CS:GO training group and a control group first, and then run the study procedure with trained and inexperienced players. Second, we found that more experienced gamers, who displayed higher confidence in their skills, and who eventually achieved higher scores had higher levels of HR. Thus, this study indicates that a stronger physiological response predicts better performance. This observation can be surprising to some individuals who might expect that stress impedes performance and high physiological arousal (e.g., increased HR) indicates a self-regulation failure and predicts adverse outcomes (e.g., Bouton, Mineka, & Barlow, 2001). Thus, findings of our study can serve as a persuasive argument that can counteract such beliefs, i.e., higher arousal predicts better performance. This can contribute to the reappraisal of the arousal method of performance improvement (Jamieson, Mendes, & Nock, 2013; Moore, Vine, Wilson, & Freeman, 2015) and facilitate stress response optimization (Jamieson, Crum, Goyer, Marotta, & Akinola, 2018). Reappraisal arousal involves building a positive attitude towards stress-related physiological responses with a focus on their facilitative effects. Current findings support this notion and can be persuasive in building a mindset that is more resilient to stress and its physiological manifestations.

The study has limitations. First, we studied male gamers due to their predominance among pro-gamers (Entertainment Software Association, 2018; Kim, 2017). Thus, our findings are generalized to male gamers; future studies might indicate whether the results generalize to women. Second, we observed gamers in real-life action, with high muscular tension and rapid motoric activity. This increases the ecological validity of the findings at the cost of measurement precision. Participants' physiological responses to motoric efforts might have interfered with physiological responses to cognitions and emotions that were the primary targets of the study. Third, baseline HR levels in our study were significantly higher than resting HR among healthy individuals (Nunan et al., 2010), and we observed non-significant gaming reactivity relative to the baseline. The reasons for this phenomenon are difficult to determine with the current procedure where we did not collect participants' baseline HR levels before the day of the tournament. Noteworthy, we compared participants' baseline HR against a published normative resting HR – a strategy that might not reflect the right resting HR of the participants. However, our *ad hoc* hypothesis might be that competing individuals were less motivated to down-regulate their arousal. This is a caveat for the interpretation of the results from the perspective of the biopsychosocial model. Further studies might provide more directive informational strategy to guide the participants how to achieve greater relaxation before the performance. Consequently, true resting capacity of the participants might be assessed and accounted for in the analysis of reactivity. Fourth, we did not measure blood pressure and, in turn, we were not able to calculate TPR – a hemodynamic index that is also indicative of challenge and threat physiological response. Measuring blood pressure would have been problematic within the study context because participants used both hands during the game. However, a recent meta-analysis indicated that CO and TPR are equally predictive of performance when used independently, and superior to the use of the combination of CO and TPR (i.e., challenge/threat index) (Behnke & Kaczmarek, 2018). Fifth, we had no control group that received no feedback or neutral feedback. We used a repeated-measures design that had a neutral pre-test, thus we were able to test whether the positive group significantly increased and the negative group significantly decreased their evaluations relative to the neutral initial conditions. A neutral control group would provide additional information regarding spontaneous changes that were likely to occur between T1 and T2 measurements. A control group would serve as a stronger reference point for testing the strength and direction of effects of experimental manipulation. Finally, rather than asking about general cognitions (e.g., "How demanding do you expect the task to be"), we aimed to be specific and ask about the task-related social challenge and threat factors, i.e., how other individuals are perceived in the context of the tournament. Consequently, we were able to pinpoint the social task-related threat and challenge evaluations: the ratio of individual skills relative to the skills of other gamers as a condition for winning the tournament. It limits the interpretation of our findings because the general challenge and threat evaluations (Do I have sufficient resources to win this tournament?) included other factors, e.g., is related to personality traits (Penley & Tomaka, 2002). However, we believe that this approach contributes to the literature by indicating that asking about more specific task-related evaluations provides meaningful findings.

5. Conclusion

The strength of this study is that it is among the most advanced real-life accounts of esports as a novel setting for the examination of phenomena related to social psychophysiology. We sought to add to the current state-of-the-art by accounting for a real-life competitive event (Turner et al., 2012). In this way, we achieved relatively high ecological validity, similar to authentic esports tournaments with prizes (King, Delfabbro, & Griffiths, 2009). Using a multilayer approach, we were able to observe how social cognitions influence performance-related behaviours and how physiological responses mediate these effects.

Declarations of interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.psychsport.2019.101584.

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