

The Influence of Positive Emotions on Cardiovascular Recovery in Esports

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Abstract

Exposure to heightened physiological arousal has been associated with an increased risk of stress-related illnesses. As such, the ability to effectively downregulate the physiological stress response is critical for maintaining long-term health. Competitive environments - such as traditional sports and esports - regularly expose individuals to high-pressure situations, highlighting the need for effective recovery strategies. According to the undoing hypothesis, the induction of positive emotions may accelerate physiological recovery following stress. While this idea is theoretically appealing, empirical findings on the efficacy of the undoing effect remain mixed. The present study investigated whether positive emotions optimize cardiovascular recovery following a highly engaging esports performance. Participants played a 10-minute match of Counter-Strike 2 (CS2), after which they watched amusing or neutral film clips. Physiological measures - including heart rate (HR), pre-ejection period (PEP), cardiac output (CO), and heart rate variability (HRV) - were recorded continuously throughout the session. It was hypothesized that positive emotions would optimize cardiovascular recovery in both speed (i.e., faster return to baseline) and depth (i.e., greater reduction in cardiovascular activation). However, results indicated no significant effect of positive emotions on recovery in terms of speed. Gamers in both conditions required a similar amount of time to return to baseline, $t(125.22) = -0.84$; Cohen's $d = -0.14$ [-0.44; 0.19]. A multiverse analysis, which explored other time-to-baseline metrics and considered recovery in terms of depth, further supported these findings. Taken together, the results suggest that the undoing effect may not consistently manifest in the esports context. Further research is needed to clarify the physiological mechanisms underlying recovery and to advance our understanding of its role in competitive esports context.

Keywords: undoing effect, undoing hypothesis, psychophysiological downregulation, recovery, esports performance

Streszczenie

Występowanie podwyższonego pobudzenia fizjologicznego łączy się ze zwiększonym ryzykiem chorób związanych ze stresem. Zdolność do skutecznego obniżenia fizjologicznej reakcji stresowej jest więc kluczowa dla utrzymania zdrowia długofalowo. Środowiska o charakterze rywalizacyjnym - takie jak tradycyjny sport i e-sport - regularnie narażają jednostki na sytuacje wysokiego napięcia, co wskazuje na potrzebę opracowania skutecznych strategii regulacji. Zgodnie z hipotezą wycofywania zmian (ang. *undoing hypothesis*), wzbudzenie pozytywnych emocji może ułatwiać fizjologiczną regenerację po stresie. Choć koncepcja ta wydaje się uzasadniona teoretycznie, wyniki badań empirycznych dotyczących skuteczności efektu wycofywania zmian pozostają niejednoznaczne. Celem niniejszego badania było sprawdzenie, czy pozytywne emocje wpływają na regenerację układu sercowo-naczyniowego po silnie angażującym występie e-sportowym. Uczestnicy rozegrali 10-minutowy mecz w grze Counter-Strike 2 (CS2), po czym obejrzeli pozytywny lub neutralny klip filmowy. Pomiar fizjologiczne - w tym tętno (HR), okres przedwyrzutowy (PEP), pojemność minutowa serca (CO) oraz zmienność rytmu serca (HRV) - były rejestrowane w sposób ciągły przez cały czas trwania badania. Przetestowano hipotezę, że pozytywne emocje sprzyjają szybszej i głębszej regeneracji układu sercowo-naczyniowego (tj. szybszemu powrotowi do poziomu bazowego oraz większemu spadkowi aktywacji fizjologicznej). Wyniki nie wykazały jednak istotnego wpływu pozytywnych emocji na szybkość regeneracji. Gracze w obu warunkach potrzebowali podobnej ilości czasu na powrót do stanu bazowego, $t(125.22) = -0.84$; d Cohena = -0.14 [-0.44 ; 0.19]. Analiza multiwersum (ang. *multiverse analysis*), która uwzględniła alternatywne miary czasu powrotu do stanu bazowego oraz głębokość regeneracji, dodatkowo potwierdziła te wyniki. Łącznie sugerują one, że efekt wycofywania zmian może nie występować w sposób konsekwentny w kontekście e-sportu.

Konieczne są dalsze badania w celu lepszego zrozumienia mechanizmów fizjologicznych leżących u podstaw regeneracji oraz jej roli w warunkach rywalizacji e-sportowej.

Słowa kluczowe: efekt wycofywania zmian, hipoteza wycofywania zmian, fizjologiczna regulacja stresu, regeneracja, występ e-sportowy

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List of Abbreviations / Glossary

ANS - Autonomic Nervous System

BMI - Body Mass Index

Bpm - Beats per minute

CO - Cardiac Output

CS: GO - Counter-Strike: Global Offensive

CS2 - Counter-Strike 2

DBP - Diastolic Blood Pressure

DVC - Dorsal Vagal Complex

ECG - Electrocardiography

EEG - Electroencephalography

ESL - Electronic Sports League

FPA - Finger Pulse Amplitude

FT - Fingertip Temperature

GABA - Gamma-aminobutyric acid

GAS - General Adaptation Syndrome

GDT - Gaming Disorder Test

HPA - Hypothalamic-Pituitary-Adrenal axis

HR - Heart Rate

HRV - Heart Rate Variability

IAPS - International Affective Picture System

IBIs - Interbeat intervals

ICD-11 - International Classification of Diseases 11th Revision

ICG - Impedance Cardiography

IL-6 - Interleukin-6

LAN - Live tournaments

MAD - Median Absolute Deviation method

MAP - Mean Arterial Pressure

PEP - Pre-ejection Period

PGL - Professional Gamers League

PNS - Parasympathetic Nervous System

PTE - Pulse Transmission Time to Ear

PTF - Pulse Transmission Time to Finger

SAM - Sympathetic-Adrenomedullary System

SBP - Systolic Blood Pressure

SCL - Skin Conductance Level

SES - Social Engagement System

SMI - Synergistic Mindsets Intervention

SNS - Sympathetic Nervous System

RMSSD - Root-Mean-Square of Successive Difference

RR - Respiratory Rate

RSA - Respiratory Sinus Arrhythmia

TPR - Total Peripheral Resistance

VC - Ventricular Contractility

VU-AMS - Vrije Universiteit Ambulatory Monitoring System

VVC - Ventral Vagal Complex

Positive emotions are strongly associated with optimal functioning across various life domains, including social relationships, education, and occupational settings (Lyubomirsky et al., 2005). In addition to promoting well-being (Seligman, 2011), positive emotions serve as a buffer against stress (Demorest, 2020) and are linked to improved cardiovascular health (Pressman et al., 2019). One physiological function of positive emotions - commonly referred to as the undoing hypothesis or undoing effect - aligns with broader research on health and well-being. According to this hypothesis, positive emotions accelerate physiological recovery following negative affect (Fredrickson & Levenson, 1998).

Effectively terminating the stress response is essential for long-term health. Chronic exposure to heightened physiological arousal can lead to exhaustion and an increased vulnerability to stress-related illnesses (Selye, 1946, 1950). High-pressure environments, such as traditional sports and esports, frequently expose individuals to such stress. As a result, athletes and esports competitors alike seek effective strategies to regulate stress. The undoing hypothesis suggests that inducing positive emotions may be one such strategy.

The present study aimed to examine the effects of positive emotions on physiological recovery following esports performance. It was hypothesized that positive emotions would optimize cardiovascular recovery both in terms of speed (i.e., faster return to baseline) and depth (i.e., greater reduction in cardiovascular activation). The first chapter introduces the undoing effect within the context of physiological research. The subsequent three chapters frame the undoing effect within affective theory, the physiology of stress and emotion, and the broader health psychology literature. Chapter five presents esports as a psychophysiological context for studying emotions. Chapter six outlines the study's methodology and data analysis strategy, detailing the procedures, measures, materials, operationalization of variables, and analytical approaches employed. The final chapters present the study's findings and discuss their implications.

Chapter 1. Undoing Effect of Positive Emotions

The undoing hypothesis, introduced by Fredrickson and Levenson (1998), was the first theoretical framework to explicitly examine the physiological effects of positive emotions. It is grounded in the observation that, unlike negative emotions, “positive emotions, such as happiness, amusement, and contentment, do not appear to elicit autonomic responses” (Levenson, 1999, p. 494). According to this hypothesis, positive emotions help to undo - that is reverse or downregulate - the physiological arousal elicited by negative affective states such as stress or fear (Levenson, 1988), thereby restoring psychophysiological balance in both mind and body.

The undoing hypothesis explicitly connects positive emotional states to mechanisms of physiological recovery (Fredrickson & Levenson, 1998). According to this framework, negative and positive emotions are linked to different patterns of autonomic nervous system (ANS) activity, serving distinct adaptive functions. Negative emotions, such as fear and anger, are evolutionary responses to threat that trigger sympathetic activation, preparing the body for action - commonly known as the fight-or-flight response. In contrast, positive emotions broaden the thought-action repertoire and support the development of cognitive, emotional, and social resources in safe environments, where autonomic regulation shifts toward parasympathetic dominance - the rest-and-digest mode (Fredrickson, 2013). The undoing effect proposes that positive emotions accelerate recovery from stress-related arousal (Fredrickson et al., 2000; Fredrickson & Levenson, 1998), primarily through parasympathetic activation, which counteracts the physiological changes driven by the sympathetic nervous system (SNS) (Cosley et al., 2010; Porges, 2011; Pressman & Cohen, 2005).

However, the degree of parasympathetic engagement may vary depending on the type of positive emotion. Social emotions, such as love and attachment, appear to produce particularly strong parasympathetic effects, aligning with their evolutionary role in fostering

safety, bonding, and long-term resource-building (Porges, 1998, 2003). Positive emotions, such as contentment and amusement, also produce soothing effects (Fredrickson, 2013). Beyond their immediate stress-buffering effects, positive emotions may also yield long-term health benefits by mitigating chronic sympathetic activation, thereby reducing negative impact of prolonged stress on the hypothalamic-pituitary-adrenal (HPA) axis (Folkman, 1997, 2008).

Empirical research supports these claims, linking positive emotions to improved cardiovascular health (Boehm & Kubzansky, 2012; Pressman & Cohen, 2005; Pressman et al., 2019), reduced systemic inflammation (Jones & Graham-Engeland, 2021), lower disease susceptibility (Pressman & Cohen, 2005), and greater pain tolerance through decreased physiological reactivity to stress (Ong et al., 2015). These findings reinforce the view that positive emotions serve as physiological buffers, reducing both subjective emotional distress and physiological strain associated with SNS activation.

Measuring the Undoing Effect

The literature identifies two primary approaches to operationalizing and analyzing the undoing effect: the change score approach and the time-to-baseline approach (Fredrickson & Levenson, 1998; Gruber et al., 2011). Both approaches have been widely used in studies investigating the undoing effect (Behnke et al., 2023). However, they are rarely applied within the same study, limiting the opportunity to explore their potentially complementary insights (Behnke et al., 2023).

Change Score Approach

The change score approach captures the difference in physiological activity between two discrete time points, for example, between stress-induction phase and the recovery phase. The change score is typically calculated by subtracting the physiological value during

recovery from either the reactive or baseline value. Higher scores indicate more effective physiological recovery (Behnke et al., 2023).

Time-to-Baseline Approach

The time-to-baseline approach assesses the duration required for the ANS to return to, and remain within, a participant's baseline physiological range (Behnke et al., 2023). This index is calculated using each participant's baseline values (defined as the mean \pm one standard deviation) and the time it takes for physiological responses to return to this range and remain there for at least five out of six consecutive seconds (Fredrickson & Levenson, 1998). An related measure, time-in-baseline, quantifies the total number of seconds a participant remains within the baseline range (Gilbert et al., 2016).

Physiological Studies on the Undoing Effect

The first study to introduce the undoing effect aimed to examine how different emotional states influence cardiovascular recovery following a fear-inducing film (Fredrickson & Levenson, 1998). Participants ($N = 60$) were fitted with physiological sensors to measure cardiovascular responses and initially watched the film clip *Ledge*, which elicited fear by depicting a man dangerously navigating the ledge of a skyscraper. Immediately afterward, participants were randomly assigned to view one of four film clips: *Waves* (eliciting contentment), *Puppy* (eliciting amusement), *Sticks* (neutral), or *Cry* (eliciting sadness) (Fredrickson & Levenson, 1998).

Physiological measures included (a) heart period (HP) - interbeat intervals (IBIs) measured using chest electrodes; (b) pulse transmission times (PTF and PTE) - indicators of cardiac contractility and vascular flexibility, assessed via photoplethysmography on the finger and ear; and (c) finger pulse amplitude (FPA) - an index of peripheral vasoconstriction based on fingertip blood flow (Fredrickson & Levenson, 1998). Participants also used a rating dial to report moment-by-moment emotional experiences. Recovery was defined as the time

required for each participant's physiological responses to return to baseline and remain stable. To summarize the physiological responses, an aggregate recovery index was computed by averaging recovery times across all cardiovascular measures that had shown significant changes during the fear-inducing film (Fredrickson & Levenson, 1998).

The results revealed that positive emotions accelerated cardiovascular recovery (Fredrickson & Levenson, 1998). Participants who viewed the contentment (*Waves*) or amusement (*Puppy*) clips returned to baseline levels significantly faster than those who viewed the neutral (*Sticks*) or sad (*Cry*) clips. These pioneering findings offered the first empirical support for the undoing effect, demonstrating the role of positive emotions in facilitating physiological recovery from negative affective states (Fredrickson & Levenson, 1998).

The undoing effect was replicated in a subsequent study examining the influence of positive emotions on physiological recovery following stress (Fredrickson et al., 2000). Participants (sample 1: $N = 95$; sample 2: $N = 75$) took part in a stress-inducing speech preparation task, which reliably elicited anxiety, as confirmed by self-report measures. Following the task, participants were randomly assigned to view one of four film clips designed to elicit contentment (*Waves*), amusement (*Puppy*), neutrality (*Sticks*), or sadness (*Cry*; shown only in sample 1) (Fredrickson et al., 2000).

Cardiovascular responses were continuously recorded across six indices (a) heart rate (HR) - measured via electrocardiography (ECG) using electrodes placed on the chest; (b) FPA - measured via photoplethysmography to assess peripheral blood flow in the finger; (c) PTF and PTE - time intervals from the electrocardiography R-wave to pulse wave upstroke at the finger and ear, indicating cardiac contractility and vascular flexibility; and (d) systolic and diastolic blood pressure (SBP and DBP) - assessed beat-by-beat using a Finapres blood pressure monitor to assess sympathetic activation (Fredrickson et al., 2000). Recovery was

again defined as the time required for each participant's physiological responses to return to baseline and remain stable. An aggregate recovery index was calculated by averaging recovery times across all cardiovascular measures that exhibited significant stress-induced changes. The speech task elicited marked increases in HR, blood pressure, and peripheral vasoconstriction, consistent with SNS activation (Fredrickson et al., 2000).

As in the previous study (Fredrickson & Levenson, 1998), the results showed that participants who viewed the contentment (*Waves*) or amusement (*Puppy*) film clips recovered significantly faster than those in the neutral or sadness conditions (Fredrickson et al., 2000). This study provides further support for the undoing effect, demonstrating that positive emotions can mitigate the physiological impact of stress and promote faster cardiovascular recovery (Fredrickson et al., 2000). Subsequent replication attempts of the undoing effect are summarized in Table 1.

Table 1*Studies on the Undoing Effect of Positive Emotions*

Study	<i>N</i>	Stress task	Positive emotions elicitation	Physiology	Undoing effect
Hannesdottir, 2007	88	Speech preparation task	Film clip and memory recall	HR	Not supported
Sokhadze, 2007	29	Aversive images	Music	HR, RR, SCL	Partially supported
Kaczmarek, 2009	69	Mental arithmetic task	Images	HR, SBP, DBP	Not supported
Alvarsson et al., 2010	42	Mental arithmetic task	Nature sounds	SCL, HRV	Indirectly supported
Radstaak et al., 2011	110	Mental arithmetic task with harassment	Film clip	HR, SBP, DBP	Not supported
White, 2013	186	Anger recall task	Images	CO, HR, RSA, TPR	Partially supported
Radstaak et al., 2014	123	Mental arithmetic task with harassment	Music	HR, SBP, DBP	Not supported
Soenke, 2014	123	Writing task	Reading task	HR, RSA	Not supported
Medvedev et al., 2015	45	Arcade task and a Stroop task or arithmetic task	Sounds	HR, SCL	Supported
Gilbert et al., 2016	83	Reward sensitivity task	Film clip	HR, PEP, RSA, FPA	Partially supported

Kaczmarek et al., 2019	162	Speech preparation task	Images	HR, SBP, DBP, TPR, CO, FT, RR, SCL	Partially supported
Quin et al., 2019	165	Public speaking task	Images	HR, SBP, DBP	Partially supported
Lautenbach & Zajonz, 2023	46	Trier Social Stress Test, Wingate Test, and a simulated competition	Guided imagery	HR, HRV, SBP, DBP	Partially supported
Kaczmarek et al., 2024	123	Speech preparation task	Images	HR	Not supported

Note. Studies were classified as undoing effect replication attempts if they involved the experimental induction of positive or neutral emotional states following experimentally induced negative emotions or stress, accompanied by the collection of physiological measures, without incorporating emotion regulation strategies or other interventions that might influence physiological or emotional outcomes.

Abbreviations of physiological indicators: CO - cardiac output, DBP - diastolic blood pressure, FPA - finger pulse amplitude, FT - fingertip temperature, HR - heart rate, HRV - heart rate variability, PEP - pre-ejection period, RR - respiration rate, RSA - respiratory sinus arrhythmia, SBP - systolic blood pressure, SCL - skin conductance level, TPR - total peripheral resistance.

The Undoing Effect: Review-Based and Meta-Analytic Conclusions

A recent review of the undoing effect highlighted methodological variability and mixed empirical support for the effect of positive emotions on physiological recovery (Cavanagh & Larkin, 2018). Of the 24 studies reviewed, eight fully supported the undoing effect (Fredrickson & Levenson, 1998; Fredrickson et al., 2000; Tugade & Fredrickson, 2004; Waugh et al., 2012; Yuan et al., 2010), another eight provided partial support (Dowd et al., 2010; Gilbert et al., 2016; Kraft & Pressman, 2012; Medvedev et al., 2015; Ong & Allaire, 2005; Papousek et al., 2010; Steptoe et al., 2007; Sokhadze, 2007), and the remaining eight found no evidence for the undoing effect (Cavanagh, 2016; Deiss, 2012; Hannesdóttir, 2007; Kaczmarek, 2009; Monfort, 2012; Purdum, 2010; Soenke, 2014; Stroup, 2015).

Variation in the type, intensity, and duration of stressor likely contributed to these mixed findings (Cavanagh & Larkin, 2018). Stress-inducing tasks ranged from active challenges (e.g., speech preparation) to passive exposure (e.g., films), with inconsistent results even within categories. For instance, among eight studies that used speech preparation as a stressor, only four fully supported the undoing effect (Fredrickson et al., 2000; Tugade & Fredrickson, 2004), while the remaining studies offered only partial or no support (Deiss, 2012; Dowd et al., 2010; Hannesdóttir, 2007; Monfort, 2012).

Positive emotion inductions also varied considerably, ranging from passive exposure such as watching films and images to active tasks like smiling or recalling positive experiences (Cavanagh & Larkin, 2018). While films and images were the most frequently used, only three studies employing these methods offered full support for the undoing effect (Fredrickson & Levenson, 1998; Fredrickson et al., 2000). Active tasks were even less consistent, with only one study (Yuan et al., 2010) showing full support. Moreover, studies

that did not experimentally induce positive affect observed the undoing effect in only half of the cases (Cavanagh & Larkin, 2018).

Definitions of recovery varied significantly across studies, further complicating efforts to compare outcomes (Cavanagh & Larkin, 2018). Seven studies employed a time-to-baseline method, defining recovery as the time required for physiological markers to return to baseline and remain stable for five out of six consecutive seconds (Fredrickson & Levenson, 1998; Fredrickson et al., 2000; Hannesdóttir, 2007; Tugade & Fredrickson, 2004). Six of these seven studies supported the undoing effect. In contrast, among the remaining 17 studies that used alternative recovery definitions, only two provided full support (Waugh et al., 2012; Yuan et al., 2010), while 15 showed either partial or no support (Cavanagh & Larkin, 2018).

A recent meta-analysis on the undoing effect reviewed 15 articles, encompassing 16 studies and 27 emotions, yielding 72 effect sizes based on data from 1,220 participants (Behnke et al., 2023). Only studies meeting strict inclusion criteria were analyzed. Specifically, eligible studies had to involve experimentally induced positive or neutral emotional states following experimentally induced negative emotions or stress, along with the collection of physiological measures. Studies were excluded if they involved deliberate emotion regulation rather than spontaneous emotional responses, included additional manipulations that might influence physiological or emotional outcomes (e.g., physical exercise prior to emotion induction), or lacked sufficient data to calculate effect sizes (Behnke et al., 2023).

The most frequently examined positive emotions were contentment, amusement, and mixed positive affect. Negative affect was most often induced through speech preparation tasks, arithmetic tasks, or film clips. Film clips were the most common method for eliciting positive emotions, followed by photographs and music (Behnke et al., 2023).

The undoing effect was primarily operationalized as the time-to-baseline method, followed by the mean change from stress condition, mean change from baseline, and time spent within baseline levels. In terms of physiological measures, HR was the most frequently used indicator, followed by DBP and SBP, composite index of ANS reactivity, SCL, CO, PEP, and TPR (Behnke et al., 2023).

The results of this meta-analysis (Behnke et al., 2023) are consistent with earlier review (Cavanagh & Larkin, 2018), indicating that the undoing effect is not reliably replicated. The key takeaway is that future research should focus on addressing foundational methodological questions, such as (a) which physiological indicators are most effective for capturing the undoing effect?; (b) which induction procedures yield the most robust responses?; and (c) how should physiological recovery be most appropriately operationalized? (Behnke et al., 2023) Clarifying these questions is crucial for advancing the theoretical development of the undoing effect - particularly given the small number of studies ($N = 16$) that met the rigorous inclusion criteria in this meta-analysis (Behnke et al., 2023).

Physiological Challenges in Undoing Effect Research

Studying emotion through the lens of physiological responses provides valuable insights into the interplay between affective states and the ANS. However, this area of research is accompanied by significant methodological challenges that impact both the broader field of emotional psychophysiology and specific frameworks such as the undoing effect. Although the undoing effect is theoretically compelling, it is hindered by several unresolved methodological concerns. This section synthesizes the key challenges and emphasizes the critical issues that must be addressed to advance the understanding of emotion-physiology dynamics.

Emotional vs. Non-Emotional Reactivity in the Autonomic Nervous System

Studying the ANS in relation to emotional experiences presents considerable methodological challenges due to the system's complexity, the wide array of functions it serves, and the high noise-to-signal ratio in physiological activity (Levenson, 2014). The ANS continuously regulates internal bodily processes in response to both homeostatic demands (e.g., maintaining blood pressure, digestion) and emotional experiences. It is also highly reactive to non-emotional environmental factors and physiological disruptions (Levenson, 2014), as well as behavioral influences such as speech, physical movement, social interaction, and cognitive load (Bradley, 2009; Britton et al., 2006; Sherwood et al., 1990).

To accurately examine emotion-related physiological responses, it is essential to distinguish them from non-emotional physiological fluctuations (Levenson, 2014). This requires careful preprocessing of physiological data to eliminate artifacts caused by coughing, sneezing, talking, or movement, which may obscure meaningful patterns (Sherwood et al., 1990). A commonly used strategy to validate the emotional relevance of physiological changes is to pair physiological data with self-reported emotional experiences.

Moreover, ensuring the validity of neutral conditions is particularly important when interpreting autonomic activity. In affective science - and especially in undoing effect research - this aspect is often underexplored. Among the reviewed studies, only two explicitly assessed whether their control conditions were genuinely neutral (Behnke et al., 2023). For instance, Gilbert et al. (2016) reported that their so-called neutral condition elicited mildly negative affect compared to baseline, whereas Fredrickson et al. (2000) successfully validated their neutral condition as emotionally neutral. Similarly, Kaczmarek et al. (2024) examined the neutrality of their control condition and found it to be mildly positive. Without empirically confirming the emotional neutrality of control conditions, researchers risk misattributing observed autonomic shifts to emotional processes when they may, in fact, reflect subtle non-

affective factors such as physical adjustments, yawning, or sneezing (Levenson, 2014; Sherwood et al., 1990).

Autonomic responses to emotion can also vary across individuals due to stable, trait-level physiological differences (Levenson, 2014). These differences may arise from non-autonomic factors such as body mass, vascular health, or baseline ANS function. Implementing stringent exclusion criteria and accurate baseline assessments can support control for such individual variability and improve the reliability of results (Levenson, 2014).

Complicating matters further, autonomic responses are increasingly understood to be context-dependent rather than strictly emotion-specific (Barrett, 2013; Quigley & Barrett, 2014). That is, physiological activity may reflect situational demands rather than the emotional state itself. This has important implications for undoing effect research - whether a positive emotion facilitates physiological recovery may depend on the specific context in which it arises.

Emotional Intensity and Ecological Validity in Contemporary Affective Research

Emotional responses tend to be most distinct when individuals experience discrete, clearly defined emotions (Tooby & Cosmides, 1990). Early research often relied on real-world, high-stakes scenarios to induce such states, such as Milgram's obedience experiments or Zimbardo's prison simulation. Due to ethical constraints, however, contemporary studies favor controlled and ethically permissible emotion-induction techniques, including film clips, images, music, autobiographical recalls, and facial expressions (Levenson, 2014). While these approaches are widely used and convenient, they often elicit weaker, more transient, and less prototypical emotional states than those encountered in naturalistic settings (Levenson, 2014). Emotional responses, especially those elicited by narrative-driven stimuli like films, tend to develop gradually as participants process the evolving story (Kaczmarek et al., 2021). This temporal delay is problematic in recovery studies, where emotional induction and recovery

are expected to occur within a limited time window. If the positive emotion unfolds too slowly, its ability to facilitate recovery may be misaligned or diminished.

A major limitation of many undoing studies is the reliance on non-personal stimuli, which may lack ecological validity and fail to resonate with participants. Barbara Fredrickson emphasized that the type of emotional stimulus matters for eliciting the undoing effect (Fredrickson et al., 2000). A recent meta-analysis confirmed that most studies used passive tasks such as watching films or viewing pictures - approaches that may not engage participants deeply (Behnke et al., 2023). This has prompted calls for more active and personally meaningful stimulus. For example, esports gameplay offers a highly engaging and emotionally immersive platform with personal meaning for players, making it an ideal context for studying psychophysiological reactions.

The Ambiguity of Heart Rate in Emotional Physiology

HR remains one of the most commonly used indicators of autonomic activity in emotion research (Behnke et al., 2023; Kreibig, 2010). However, it offers only a partial view of the complex physiological processes underlying emotions (Levenson, 2014). Heart function is regulated by three main factors (a) the sinoatrial node, which sets the intrinsic HR at approximately 100 bpm (Jose & Collison, 1970); (b) parasympathetic input via the vagus nerve, which slows the heart; and (c) sympathetic input, which accelerates it. At rest, parasympathetic influence dominates, typically lowering the HR to around 60 bpm. Emotional stimuli can influence this autonomic balance in complex and variable ways.

The SNS and parasympathetic nervous system (PNS) often interact in dynamic ways, such as coactivation (simultaneous engagement) or coordinated withdrawal (increased activity in one system alongside decreased activity in the other) (Berntson, 2019; Berntson et al., 1991; Levenson, 2014). These interaction complicates HR interpretation, as changes may result from increased sympathetic activation, reduced parasympathetic activity, or both

(Levenson, 2014). More nuanced physiological markers are essential - particularly in undoing research, where many studies still rely primarily on HR (Behnke et al., 2023).

To assess cardiac contractility and vascular resistance researchers commonly use impedance cardiography (ICG) (Sherwood et al., 1990). This tool passes a low-voltage current through the chest and measures changes in impedance, allowing researchers to estimate PEP (the time between ventricular depolarization and aortic valve opening), CO (the amount of blood ejected by the heart during one minute) and HRV (the variation in time intervals between consecutive heartbeats). The PEP in particular, is considered a reliable and relatively pure marker of SNS activity, while HRV is considered a marker of PNS activity (Levenson, 2014). Despite its utility, ICG has been underutilized in undoing research (Behnke et al., 2023), and CO and PEP - physiological indicators of task engagement - have appeared in only three published studies (Gilbert et al., 2016; Kaczmarek et al., 2019; White, 2013).

To undo or not to undo?

The undoing hypothesis offers a compelling framework for understanding how positive emotions may facilitate physiological recovery from stress. However, the development of this research area has been constrained by several methodological limitations and unresolved questions. These include variability in affect induction methods (e.g., differences in emotional intensity and personal relevance), inconsistent definitions and operationalizations of recovery, an overreliance on HR as the primary physiological marker, and limited use of ICG to assess more nuanced cardiovascular dynamics.

This doctoral thesis aimed to address these challenges. The present study was conducted within the esports context - a meaningful, emotionally engaging, and physiologically arousing setting. ICG was employed to assess complex physiological processes and examine the underlying mechanisms of the undoing effect. Furthermore, multiple operationalizations of recovery were explored and diverse analytical strategies

applied to assess the impact of positive emotions on physiological recovery in esports context. Through this approach, this research contributes to a more refined understanding of the undoing effect.

Chapter 2. Framing Undoing Effect Within Affective Science

Positive emotions are defined by their positive valence, or the pleasure they evoke in response to a stimulus, such as an object, event, or experience. This positive valence typically arises from favorable circumstances, including smiling faces or amusing situations (Lang et al., 1997; Marchewka et al., 2014). Certain positive emotions are linked to specific contexts. For instance, amusement occurs in response to humorous stimuli (Kreibig et al., 2013), while attachment love emerges from affiliative and intimate interactions (Shiota et al., 2017). Awe arises when individuals encounter vast, information-rich stimuli that challenge existing knowledge (Shiota et al., 2017), and contentment follows the fulfillment of a need, the acquisition of a resource, or acceptance of one's current circumstances (Shiota et al., 2017). Excitement often accompanies novelty, challenges, or achievements, particularly when some element of risk is present (Cowen & Keltner, 2017; Ekman & Cordaro, 2011). Gratitude occurs in response to unexpected kindness or generosity (Ekman & Cordaro, 2011; McCullough et al., 2001). Joy stems from positive events or a broader sense of well-being, encouraging individuals to savor the moment and seek future positive experiences (Lazarus, 1991; Roseman, 1996; Smith & Kirby, 2010). Nurturant love emerges when caring for offspring or vulnerable family members (Shiota et al., 2017), whereas pride arises from achievements that elevate social status or recognition (Tracy & Robins, 2007).

Positive emotions differ in the intensity of approach motivation, which influences behavioral tendencies (Gable & Harmon-Jones, 2010). The approach motivation drives individuals toward desired goals, objects, or situations, often linked to curiosity, attraction, or reward-seeking behaviors. By contrast, avoidance motivation leads individuals away from

undesirable or threatening stimuli, often linked to fear, discomfort, or aversion (Gable & Harmon-Jones, 2010). Physiologically, positive emotions are associated with various autonomic responses, including changes in cardiovascular, electrodermal, and respiratory activity (Behnke et al., 2022). However, debate remains as to whether these physiological patterns are unique to particular positive emotions or reflect a broader, universal response across all positive affective states (Behnke et al., 2022).

Broaden-and-Build Theory of Positive Emotions

Positive emotions - with the notable exception of hope (Fredrickson et al., 2003) - typically do not arise in life-threatening situations and therefore do not trigger specific action tendencies aimed at immediate, concrete behaviors (Fredrickson & Levenson, 1998). Instead, positive emotions activate broader, more flexible action tendencies (Fredrickson, 2013). Unlike negative emotions, which often prepare the body for urgent physical responses, positive emotions encourage individuals to explore new perspectives, engage in novel actions, and break away from habitual patterns and established routines (Fredrickson, 2013).

According to the Broaden-and-Build Theory, positive emotions expand an individual's thought-action repertoire, facilitating new perspectives and behaviors that contribute to personal growth and resource accumulation (Fredrickson, 2013). For instance, individuals who practice loving-kindness meditation report increased cognitive resources such as mindfulness, psychological resources like self-acceptance, social resources exemplified by stronger relationships, and physical resources manifested in fewer illness symptoms (Fredrickson et al., 2008). Specific positive emotions uniquely foster the development of psychological, social, and cognitive resources (Fredrickson, 2013). Joy arises in response to safe, familiar, and unexpectedly positive experiences. It encourages play and active engagement, fostering the development of new skills through experiential learning. Gratitude emerges when one receives a gift or benefit. It promotes a prosocial and creative urge to

reciprocate, supporting the development of care, loyalty, and strong social bonds.

Contentment occurs in response to safe, familiar, and low-effort situations. It encourages savoring the moment and integrating the experience, facilitating the formation of new priorities and personal perspectives (Fredrickson, 2013). Interest is elicited by stimuli that are both safe and novel. It motivates exploration and learning, enabling the acquisition of new knowledge. Hope arises in situations marked by fear of negative outcomes but accompanied by a longing for improvement. It motivates future-oriented thinking and planning, and supports resilience and optimism. Pride follows socially valued achievements. It inspires individuals to dream ambitiously and strengthens achievement motivation (Fredrickson, 2013). Amusement results from the perception of non-serious social incongruity. It encourages the sharing of laughter and lightheartedness, contributing to the formation and maintenance of social bonds. Inspiration is triggered by witnessing human excellence or virtue. It stimulates the desire to pursue one's own higher potential and supports personal growth. Awe arises in the presence of vast beauty or moral goodness. It encourages absorption and cognitive accommodation, facilitating the expansion of one's worldview. Love encompasses many of the above emotions when experienced within an interpersonal interactions. It encourages mutual care and the co-experience of joy, gratitude, hope, and other positive states - particularly reinforcing the creation and maintenance of social bonds (Fredrickson, 2013). These psychological resources contribute to greater resilience and optimal functioning (Fredrickson & Joiner, 2002; Cohn et al., 2009). Positive emotions improve one's capacity to find meaning in life events, which helps sustain positive affect, reduce stress, foster emotional development, and build resilience in the face of adversity (Fredrickson, 2013). Moreover, positive emotional experiences initiate a reinforcing cycle - often referred to as an *upward spiral* - that increases the likelihood of experiencing further

positive emotions. This process supports and enhances long-term emotional well-being (Fredrickson, 2013; Fredrickson & Joiner, 2002).

Broaden-and-Build Theory marked one of the earliest efforts to explore the physiological functions of positive emotions. In their foundational study on the undoing effect, Fredrickson and Levenson (1998) demonstrated that participants exposed to positive emotions recovered more quickly from an anxiety-inducing experience. Specifically, participants in the sadness condition required 60 seconds to return to baseline, those in the neutral condition 40 seconds, while participants in the amusement and contentment conditions recovered within just 20 seconds. These findings suggested that positive emotions facilitate faster physiological recovery from negative affect, leading the authors to propose that positive emotions serve to *undo* the adverse physiological effects of negative emotional states. This regulatory function - known as the undoing effect - remains one of the most extensively studied physiological function of positive emotions (Behnke et al., 2023).

Motivational Dimensional Model of Affect

While the Broaden-and-Build Theory highlights the general functions of positive emotions - expanding cognitive-action repertoires, fostering resource development, and promoting physiological soothing (Fredrickson, 2013) - the Motivational Dimensional Model of Affect offers a more differentiated view by highlighting the distinct roles of positive emotions (Gable & Harmon-Jones, 2010). This model classifies emotions along three primary dimensions - valence (positive vs. negative affect), arousal (low vs. high activation), and approach-avoidance motivation (Gable & Harmon-Jones, 2010) - which collectively shape emotional responses and guide behavior (Mauss & Robinson, 2009).

A key mechanism within this model is motivational direction, which determines whether an emotion drives approach behaviors (e.g., pursuing a desired goal) or avoidance behaviors (e.g., withdrawing from a threat) (Gable & Harmon-Jones, 2010). Motivational

intensity is another critical aspect, reflecting the strength of this urge. Within the approach dimension, emotions can range from low motivational intensity (e.g., amusement, sadness) to high motivational intensity (e.g., enthusiasm, anger) (Gable & Harmon-Jones, 2010). This interaction between valence, arousal, and motivation is central to understanding how emotions influence cognitive engagement and behavior.

Although valence and approach motivation are often positively correlated, and valence and arousal tend to be inversely related, not all emotions conform to these patterns. The Motivational Dimensional Model of Affect illustrates that emotions sharing the same valence can diverge in their approach-avoidance tendencies (Gable & Harmon-Jones, 2010). For instance, amusement elicits positive affect but does not necessarily trigger a strong approach urge, whereas desire combines positive valence with an intense motivation to pursue a goal or object (Kreibig et al., 2013). Furthermore, high-approach positive emotions (e.g., enthusiasm) tend to narrow attentional focus and promote goal-directed behavior, whereas low-approach emotions (e.g., amusement) support broader, more exploratory engagement with the environment (Li et al., 2018). Thus, examining these motivational dimensions provides deeper insight into how specific positive emotions uniquely shape cognition and behavior.

Motivational intensity closely aligns with the arousal level of affective states (Bradley & Lang, 2007). Empirical findings within the Motivational Dimensional Model of Affect supports this relationship, revealing that high-intensity motivational stimuli elicit strong arousal, while low-intensity motivational stimuli elicit substantially less arousal, sometimes comparable to neutral conditions. Nonetheless, arousal and motivation are conceptually distinct constructs (Gable & Harmon-Jones, 2010). In a study illustrating this distinction, participants completed a Navon letter task after viewing either appetitive or neutral images, with stationary physical exercise used to elevate arousal levels. Although the exercise increased physiological arousal - as evidenced by elevated HR - it did not lead to attentional

narrowing. This suggests that arousal alone does not account for the cognitive effects typically associated with motivational states (Harmon-Jones et al., 2009). Therefore, while arousal may contribute to motivational intensity, it does not fully explain its impact on attentional focus or cognitive processing (Gable & Harmon-Jones, 2010). By differentiating between arousal and motivational intensity, the Motivational Dimensional Model of Affect offers a more refined framework for understanding how emotions dynamically influence cognition and behavioral tendencies (Gable & Harmon-Jones, 2010).

Building on the Motivational Dimensional Model of Affect, this study examined the interaction between emotional valence (i.e., pleasure or displeasure) and approach-avoidance motivation (Kaczmarek et al., 2021). Student volunteers ($N = 69$) viewed a set of validated emotion-eliciting video clips and provided ratings of valence and approach-avoidance motivation. The clips were designed to evoke amusement, awe, desire, enthusiasm, tenderness, anger, fear, or neutral emotional state. Analyses revealed clear differences in emotions' valence and approach-avoidance motivation (Kaczmarek et al., 2021). Positive emotions such as amusement, awe, desire, enthusiasm, and tenderness elicited positive valence. In contrast, anger and fear elicited negative valence, while neutral stimuli resulted in neutral valence. Approach-avoidance motivation was highest for high-approach positive emotions (e.g., desire, enthusiasm), moderate for neutral stimuli, and lowest for low-approach positive emotions (e.g., amusement) and negative emotions (e.g., anger and fear). Continuous ratings demonstrated a positive relationship between valence and approach motivation - pleasant stimuli prompted stronger urges to approach, whereas unpleasant stimuli prompted withdrawal (Kaczmarek et al., 2021). Moreover, high-approach emotions exhibited greater congruence between valence and approach motivation, indicating a stronger motivational balance. In contrast, amusement and anger, were considered undermotivated showing relatively weak approach-avoidance motivation compared to their valence level. These

findings support the Motivational Dimensional Model of Affect by highlighting the role of motivational intensity in distinguishing between emotions, particularly within the domain of positive affect. They suggest that incorporating motivational intensity enhances understanding of how positive emotions vary across the affective spectrum (Kaczmarek et al., 2021).

The Motivational Dimensional Model of Affect provides a comprehensive framework for understanding the interactions between emotional valence, arousal, and approach-avoidance motivation (Gable & Harmon-Jones, 2010). This model extends the study of positive emotions by emphasizing their functional differences. Specifically, high-approach positive emotions drive goal-directed behavior, sustain motivation, and facilitate the pursuit of meaningful goals, whereas low-approach positive emotions are associated with calming and soothing effects (Gable & Harmon-Jones, 2010; Kaczmarek et al., 2019, 2021). By examining the motivational dimensions of emotions, this model offers deeper insights into how distinct positive emotions uniquely influence behavior.

Polyvagal Theory

The Polyvagal Theory offers a framework for understanding the interactions between the ANS, emotions, and social behavior (Porges, 2007). It proposes that different branches of the vagus nerve regulate distinct physiological states, shaping adaptive responses to safety and threat. Vagal withdrawal supports mobilization behaviors such as fight-or-flight, whereas increased vagal influence encourages calm physiological states that support social engagement (Porges, 2007).

Polyvagal Theory identifies three evolutionary stages of autonomic regulation, each linked to a specific adaptive function (Porges, 2007). The Social Engagement System (SES) is the most recent autonomic system based on the myelinated vagus (Ventral Vagal Complex, VVC). It regulates HR, inhibits sympathetic activity, and dampens stress responses mediated by the HPA axis. It also supports prosocial behaviors - including facial expression,

vocalization, and listening - thereby fostering connection and safety (Porges, 2007). The SNS is an older system responsible for mobilization responses such as fight-or-flight, preparing the body for threats and challenges (Porges, 2007). The Unmyelinated “Vegetative” Vagus (Dorsal Vagal Complex, DVC) is the oldest system, involved in energy conservation, digestion, and immobilization behaviors (e.g., freezing or feigning death) under extreme threat (Porges, 2007). These three circuits operate hierarchically in response to escalating threats. Under safe conditions, the SES remains dominant, promoting calm states and prosocial behavior. When safety is compromised, the SNS activates, triggering fight-or-flight responses. When the threat persists or intensify, the DVC engages, resulting in immobilization behaviors (Porges, 2007).

Neuroception: The Brain’s Safety Detection System

A key mechanism in Polyvagal Theory is neuroception, the process by which the nervous system evaluates environmental cues to detect safety or threat (Porges, 2007). Neuroception guides whether an individual engages in social interaction or defensive behaviors based on perceived risk. It relies on subcortical brain structures, including the amygdala, fusiform gyrus, and superior temporal sulcus, which detect subtle social cues - such as facial expressions, vocal tone, and body posture - to determine safety or threat (Adolphs, 2002; Winston et al., 2002). Safe contexts activate the VVC, promoting calm physiological states, social engagement, and emotion regulation (Porges, 2007). Dangerous or life-threatening contexts activate sympathetic pathways (fight-or-flight) or DVC (freezing or immobilization) (Porges, 2007).

The Social Engagement System and Emotion Regulation

The SES integrates neural pathways from cranial nerves controlling the face and head with the myelinated vagus, forming a bidirectional link between social behavior and physiological regulation (Porges, 2007). This system coordinates:

- facial expressions (emotional communication)
- vocalization and prosody (speech tone and modulation)
- middle ear function (focusing on human voices)
- HR and respiration (internal state regulation) (Porges, 2007).

This feedback loop allows social interactions to shape physiological states and vice versa. For example, listening and facial expressions can modulate HR via vagal pathways, fostering calm states (Porges, 2007).

The Vagal Brake and Adaptive Flexibility

A central regulatory mechanism in Polyvagal Theory is the vagal brake, which modulates HR by regulating sinoatrial node activity (Porges, 2007). When vagal tone is high, the HR slows, promoting calm and social engagement. When vagal tone decreases, HR accelerates, supporting mobilization behaviors. RSA, a natural fluctuation in HR synchronized with breathing, serves as an index of vagal tone (Porges, 2007).

Polyvagal Theory provides a physiological explanation for the undoing effect, illustrating how positive emotions mitigate the autonomic arousal caused by stress. The VVC is crucial in restoring calm states after stress, enhancing emotion regulation and resilience (Porges, 2007). Social emotions, such as love (Porges, 1998) and attachment (Porges, 2003), are especially effective in activating the PNS, reinforcing a sense of safety and dampening stress responses. Social engagement behaviors - such as connection and communication - further enhance parasympathetic activity, highlighting the interactions between social emotions, vagal regulation, and well-being.

Chapter 3. Framing Undoing Effect Within the Physiology of Stress and Positive Emotions

The ANS is a fundamental regulatory system that coordinates organ function to preserve health and adapt to environmental demands (Levenson, 2014). Its central functions include (a) maintaining homeostasis; (b) activating physiological systems in response to challenges and opportunities; and (c) facilitating recovery once the body returns to a baseline state. These processes are essential for survival and adaptation, positioning the ANS as a cornerstone of human physiology (Levenson, 2014).

Traditionally, the ANS is divided into two main branches: the SNS and PNS, performing distinct but complementary functions (Levenson, 2014). The SNS mobilizes the body in response to stress and heightened activity, and is best known for mediating the fight-or-flight response. It dominates during wakefulness, promoting alertness and readiness for action (Podgórska, 2023). Activation of the SNS increases brain activity by stimulating the release of neurotransmitters such as dopamine, adrenaline, and noradrenaline, while elevating cortisol levels to manage metabolism and energy distribution. The SNS also enhances blood circulation to vital organs, boosting oxygen and glucose availability for immediate action (Podgórska, 2023). To optimize energy use, it activates sweat and salivary glands, sharpens sensory perception, and temporarily suppresses digestive, excretory, and renal functions. These physiological changes collectively prepare the body to respond efficiently to external demands or perceived threats (Podgórska, 2023).

In contrast, the PNS - often referred to as the rest-and-digest or feed-and-breed system - balances the SNS by promoting relaxation, recovery, and homeostasis (Podgórska, 2023). It reduces physiological arousal, enabling a return to baseline functioning after stressful events. The parasympathetic branch supports digestive processes, nutrient absorption, and energy storage, driving glucose uptake and its conversion to glycogen in the liver and muscles to

restore energy reserves. It is most active during rest, sleep, and after meals, allowing the body to conserve resources and focus on repair and regeneration (Podgórska, 2023).

A key component of the PNS is the vagus nerve, which regulates internal organ function (Podgórska, 2023). The vagus nerve connects the heart, lungs, liver, stomach, intestines, kidneys, spleen, and gallbladder to the brain, facilitating efficient communication among these systems. It plays a critical role in regulating HR, digestion, respiratory function, and emotional balance. Proper vagal function is vital for emotional stability, social engagement, and stress resilience (Podgórska, 2023). Neurotransmitters such as acetylcholine, gamma-aminobutyric acid (GABA), and serotonin mediate parasympathetic activity, supporting relaxation and mood regulation. Through these mechanisms, the PNS fosters both physical and psychological well-being, ensuring the body can recover effectively, maintain stability, and promote long-term health (Levenson, 2014; Podgórska, 2023).

The ANS operates through a complex, integrated network of nerves, organs, and biological sensors, allowing for precise regulation of physiological states (Levenson, 2014). It acts as (a) a regulator by preserving internal stability; (b) an activator by mobilizing resources during stress or opportunity; (c) a coordinator by ensuring seamless communication between the brain and body; and (d) a communicator by producing observable physiological changes (e.g., blushing or sweating) that offer social and environmental cues (Levenson, 2014). Over both the short and long term, the ANS significantly influences health, illness, and well-being, reflecting its extensive impact on human physiology (Levenson, 2014).

Physiological responses are a fundamental component of affective experiences, complementing subjective feelings and expressive behaviors (Gross, 2015; Mauss et al., 2005). The ANS plays a central role in these responses, coordinating cardiovascular, electrodermal, and respiratory changes that accompany affective states. Behnke et al. (2022) review and described cardiac, vascular, electrodermal, respiratory, and other physiological

markers commonly used in affective science and physiological research. HR refers to the number of beats of the heart per minute and is one of the most widely used indicators of ANS activity (Behnke et al., 2022). It reflects input from both the sympathetic and parasympathetic branches of the ANS and is often interpreted as a marker of motivational intensity, action readiness, and engagement (Blascovich, 2008; Richter et al., 2016). Alternatively, heart activity can be expressed through IBIs - the average time between two consecutive heartbeats. HR can be measured using ECG, a photoplethysmograph (usually attached to the fingertip or earlobe), or a volume clamp method (blood pressure wave measured at the brachial or finger level) (Behnke et al., 2022). RSA is the variation in heart beats that follows breathing cycle (Behnke et al., 2022). It reflects PNS activity and is commonly calculated from ECG or pulse raw data using three types of analysis: (a) spectral analysis with high-frequency HRV; (b) time-domain analysis with root-mean-square of successive difference between normal heartbeats (RMSSD); and (c) geometric analysis with Poincaré plots (Behnke et al., 2022). Stroke volume (SV) refers to the amount of blood pumped by the heart with each beat (Behnke et al., 2022). It is often associated with stress and fatigue (Nelesen et al., 2008) and can be measured through ICG or estimated using blood pressure measurements via the volume clamp method (Penaz, 1973; Wesseling et al., 1995). CO is the total volume of blood the heart pumps in one minute (Behnke et al., 2022). It is used to distinguish between different types of stress responses, such as challenge versus threat (Blascovich, 2008; Behnke & Kaczmarek, 2018) and is calculated by multiplying SV by HR. PEP is the time between the onset of the heart's electrical activity and the ventricular contraction (Behnke et al., 2022). It serves as a marker of SNS activation and is closely related to motivational intensity and task engagement (Behnke et al., 2022; Blascovich, 2008; Richter et al., 2016). It is typically assessed using a combination of ECG and ICG (Behnke et al., 2022). SBP is the highest pressure during each cardiac cycle (Behnke et al., 2022) and can reflect effort investment

(Richter et al., 2016). DBP is the lowest pressure during each cardiac cycle. Both SBP and DBP are typically measured using finger, wrist, or arm cuffs with either auscultatory or oscillometric methods (Behnke et al., 2022). TPR refers to the resistance that blood encounters as it travels through the body's blood vessels (Behnke et al., 2022). Like CO, TPR helps differentiate between challenge and threat states. It can be estimated using data from ICG and blood pressure measurements or the volume clamp method (Penaz, 1973; Wesseling et al., 1995). SCL measures the skin's electrical conductivity, which increases with sweat gland activity (Behnke et al., 2022). It reflects SNS activation and is often associated with mental stress, cognitive load, and autonomic arousal (Boucsein, 2012). This measure is typically obtained using a skin conductance amplifier, which applies a small electrical current across two nearby fingers and records the resulting conductance (Behnke et al., 2022). RR - the number of breaths per minute - is another key physiological indicator (Behnke et al., 2022). It is linked to emotional states such as fear and anger (Siegel et al., 2018), as well as general arousal (Boiten et al., 1994) and mental stress (Grossman, 1983). RR can be measured using spirometry or through devices like piezo-electric belts or ICG (Behnke et al., 2022). Lastly, skin temperature refers to the temperature at the surface of the body, typically measured at the fingers or palms (Behnke et al., 2022), and reflects sympathetically mediated peripheral vasoconstriction (Rimm-Kaufman & Kagan, 1996).

In affective science, physiological markers offer valuable insights into how emotions are generated, expressed, and regulated, underscoring the ANS's central role in affective processes (Berntson et al., 1991; Cacioppo et al., 2000; Larsen et al., 2008). The undoing effect proposes that positive emotions accelerate physiological recovery following stress or negative emotional states (Fredrickson & Levenson, 1998). Accordingly, this chapter reviews the physiology of stress and positive emotions, framing the undoing effect within the broader context of affective and physiological research.

Stress Physiology in Theoretical Models

Stress is a psychophysiological state of strain that arises when an individual perceives their essential goals, responsibilities, or values as threatened, obstructed, or unattainable. It occurs in response to situations appraised as challenging, threatening, or overwhelming, triggering a cascade of neurobiological, hormonal, and behavioral changes aimed at facilitating adaptation (McEwen, 1998, 2007). The stress response involves activation of the ANS and the HPA axis, leading to the release of stress hormones such as cortisol, adrenaline, and noradrenaline (McEwen, 1998, 2007). Although stress is often perceived negatively (distress), it can also be adaptive (eustress), enhancing motivation, focus, and resilience in certain contexts (Dhabhar, 2014, 2018).

Hans Selye's General Adaptation Syndrome

Hans Selye, a pioneering endocrinologist, introduced the General Adaptation Syndrome (GAS) as a model to explain the body's physiological response to prolonged stress (Selye, 1946, 1950). GAS outlines a three-stage process through which the body attempts to maintain homeostasis when confronted with persistent stressors. During the alarm stage, the body's initial reaction to a stressor involves activation of the fight-or-flight response through the SNS. This leads to the rapid release of stress hormones (i.e., adrenaline and cortisol), producing physiological changes such as increased HR, elevated blood pressure, and heightened glucose availability to prepare for immediate action. If the stressor persists, the resistance stage follows, during which the body enters a state of adaptation. Stress hormone levels remain elevated, and energy is redirected away from non-essential functions - such as digestion and immune activity - to cope with the ongoing challenge. Prolonged exposure to stress eventually depletes the body's resources, reducing its ability to cope. The exhaustion stage is characterized by fatigue, immune suppression, and increased vulnerability to stress-related illnesses, such as cardiovascular disease and depression (Selye, 1946, 1950).

The GAS has been widely applied in fields such as occupational health, where it helps explain the development of chronic workplace stress and burnout. If left unmanaged, chronic stress can lead to significant physical and psychological consequences, including hypertension, diabetes, anxiety, and depression (Selye, 1946, 1950). The model underscores the importance of stress management strategies, such as adequate recovery periods and adaptive coping mechanisms, to prevent individuals from progressing to the exhaustion stage. However, GAS has received criticism for its biologically driven focus, as it does not account for individual differences in stress perception, emotional processing, or coping styles. While the model offers a valuable foundation for understanding the physiological aspects of stress, contemporary approaches incorporate cognitive, emotional, and social dimensions, providing a more nuanced and comprehensive understanding of the stress experience.

Lazarus and Folkman's Transactional Model of Stress and Coping

Transactional Model of Stress and Coping emphasizes the cognitive and emotional processes underlying the stress response (Lazarus & Folkman, 1987). This framework conceptualizes stress as a subjective experience shaped by how individuals evaluate and respond to their environment. Unlike the GAS, which conceptualizes stress primarily as a biological response, the Transactional Model highlights the dynamic interaction between the individual and the environment, where the perception of a situation determines whether it is experienced as stressful (Lazarus & Folkman, 1987).

The model comprises three key components. During primary appraisal, individuals assess whether an event is relevant to their well-being and categorize it as harm/loss (damage already experienced), threat (potential future harm), or challenge (an opportunity for mastery or growth). This appraisal determines whether the situation is perceived as stressful (Lazarus & Folkman, 1987). If an event is appraised as stressful, individuals evaluate their available resources to manage it during the secondary appraisal. These resources may include personal

strengths, social support, or external solutions (Lazarus & Folkman, 1987). Based on these appraisals, individuals implement coping strategies that generally fall into two primary categories (a) problem-focused coping, which involves efforts to directly addressing the stressor through problem-solving or seeking information; and (b) emotion-focused coping, which includes strategies aimed at regulating emotional responses, such as seeking social support, engaging in cognitive reframing, or practicing relaxation techniques (Lazarus & Folkman, 1987).

Folkman later expanded the model to include meaning-focused coping, which involves generating positive emotions when initial coping efforts are insufficient (Folkman, 2008). This form of coping helps individuals maintain motivation, restore psychological resources, and persist with problem-focused coping over time. Positive emotions also act as a buffer, offering temporary relief from distress and supporting more effective navigation of prolonged stress (Folkman, 2008). Notably, coping strategies influence how a stressor is appraised, thereby shaping emotional and behavioral responses (Lazarus & Folkman, 1987).

The Transactional Model offers a comprehensive framework for understanding how individuals appraise and cope with stress. It emphasizes that stress is not merely an automatic biological response but a dynamic process shaped by cognitive and emotional interpretations. This perspective has important implications for stress management, highlighting the value of interventions that promote cognitive flexibility, strengthen coping resources, and foster resilience.

The Biopsychosocial Model of Challenge and Threat

The Biopsychosocial Model of Challenge and Threat (Blascovich & Tomaka, 1996) provides a framework for understanding how individuals evaluate and respond to stress in motivated performance contexts - situations that are goal-oriented, evaluative, and often demanding. The model integrates concepts from Lazarus and Folkman's (1987) Transactional

Model of Stress and Coping, as well as Dienstbier's (1989) Physiological Toughness Model (Hase et al., 2025). It has been widely applied across various domains, including sports psychology (Moore et al., 2012, 2013, 2015, 2018), education (Chalabaev et al., 2012; Jamieson et al., 2016), and medicine (Moore et al., 2014; Vine et al., 2013), demonstrating its utility in understanding performance under pressure.

Cognitive Appraisal of Challenge and Threat. At the core of the Biopsychosocial Model is the distinction between challenge and threat states, which arise based on how individuals evaluate their personal resources (e.g., skills, experience, social support) relative to situational demands (e.g., task difficulty, time pressure, social expectations) (Blascovich & Mendes, 2010; Jamieson, 2017). These appraisals occur automatically and continuously (Quigley et al., 2002) and are influenced by factors such as task complexity, feedback, and social comparison (Hase et al., 2025).

Challenge state occurs when perceived resources meet or exceed situational demands. This state is associated with higher confidence, approach motivation, and an adaptive physiological response that supports effective performance (Blascovich, 2008; Hase et al., 2025). Threat state occurs when demands outweigh perceived resources, leading to uncertainty, heightened vigilance, and a physiological response that can hinder goal pursuit (Blascovich, 2008; Hase et al., 2025).

Physiological Markers of Challenge and Threat. The Biopsychosocial Model posits that challenge and threat states are associated with distinct cardiovascular patterns, offering objective physiological markers of psychological states and coping capacity (Seery, 2013). Although both states involve activation of the SNS - resulting in increased HR and ventricular contractility - they differ in HPA axis involvement and associated outcomes (Mendes & Park, 2014). Challenge states are characterized by activation of the sympathetic-adrenomedullary (SAM) system, which leads to the release of epinephrine, enhanced energy mobilization,

reduced TPR to support efficient blood flow, and increased CO, allowing the heart to pump more blood per minute. This physiological profile resembles that of aerobic exercise (Blascovich, 2008) and is associated with approach motivation, goal-directed behavior, and improved performance (Blascovich et al., 2004; Chalabaev et al., 2009; Seery et al., 2010; Turner et al., 2012). Threat states, in contrast, involve co-activation of the SAM and HPA systems. This results in diminished epinephrine release, limited energy mobilization, elevated TPR (which restricts circulation), and lower CO despite increased cardiac effort (Blascovich, 2008). Threat responses often trigger a vigilance or freezing response (Williams et al., 1985), which emphasizes alertness over action, elevates physiological strain, and impairs performance (Blascovich et al., 2004; Chalabaev et al., 2009; Seery et al., 2010; Turner et al., 2012).

Implications for Performance and Motivation. According to the Biopsychosocial Model, task engagement is a prerequisite for both challenge and threat responses - without a personally meaningful goal, neither state is elicited (Blascovich, 2008; Hase et al., 2025). Challenge states are linked to approach motivation, with a focus on potential gains and mastery. Threat states involve both approach and avoidance motivation, often marked by fear of failure (Chalabaev et al., 2009; Seery et al., 2009). Empirical research shows that challenge states are associated with enhanced performance, resilience, and faster recovery from stress (Behnke & Kaczmarek, 2018; Hase et al., 2019a), whereas threat states are linked to cognitive impairments, increased anxiety, slower decision-making, and long-term negative health outcomes, such as cardiovascular disease and depression (Jefferson et al., 2010; Matthews et al., 1997; McLoughlin et al., 2024).

The Biopsychosocial Model offers a scientifically robust framework for understanding how psychological appraisals shape physiological responses and influence performance outcomes. A major strength of the model is its use of objective cardiovascular markers, which

provide insight into stress responses beyond subjective self-report (Seery, 2013). For example, individuals experiencing test anxiety may underreport stress levels, but cardiovascular data may still reveal a threat response (Seery, 2013).

By distinguishing between adaptive challenge states and maladaptive threat states, the Biopsychosocial Model informs mental training programs across domains such as sports psychology, occupational health, and decision-making under pressure. Interventions that promote challenge-based appraisals - through mindset training, stress reappraisal, or performance preparation - can enhance resilience, optimize performance, and reduce long-term effects of stress, reinforcing the importance of appraisals processes in high-pressure environments.

Empirical Evidence Supporting Biopsychosocial Model. A growing body of evidence supports the model's claims regarding the performance benefits of challenge states. A meta-analysis (Behnke & Kaczmarek, 2018) and systematic review (Hase et al., 2019a) confirmed that challenge states consistently predict superior performance across multiple domains. Dixon et al. (2020) found that elite soccer players with blunted cardiovascular responses underperformed compared to those exhibiting clear challenge or threat patterns. Jewiss et al. (2023) demonstrated that challenge states improved cricket batting performance, though this did not extend to season-long outcomes (Jewiss et al., 2024). McCreary et al. (2020) manipulated challenge-threat appraisals in elite junior cricket batsmen and found that all participants in the challenge condition completed the task successfully, whereas only one in the threat condition did. Hase et al. (2019b) found that l-tyrosine supplementation helped individuals in a threat state maintain optimal performance, although it did not shift their appraisal to challenge state. A recent meta-analysis (Hase et al., 2025) spanning 62 studies and 7,418 participants confirmed that challenge states were positively associated with better

performance outcomes across education, sport, and other high-stakes settings, while threat appraisals predicted poorer performance (Hase et al., 2025).

Meta-Analytic Perspectives on the Physiology of Positive Emotions

Affective scientists widely acknowledge the link between emotions and ANS activity and continue to explore this relationship. Kreibig (2010) conducted a comprehensive qualitative review of 134 studies examining ANS responses to experimentally induced emotions in healthy individuals. Among the most commonly used emotion elicitation methods were film clips, personalized recall, real-life manipulations, picture viewing, and standardized imagery. Among the most frequently assessed physiological indices were cardiovascular measures, with HR being the most commonly reported marker. The review identified distinct ANS patterns for six negative emotions (anger, anxiety, disgust, embarrassment, fear, sadness) and eight positive emotions (affection, amusement, contentment, happiness, joy, anticipatory pleasure, pride, relief) (Kreibig, 2010).

The findings supported the view that emotions are associated with specific ANS patterns, rather than a single, undifferentiated physiological response (Kreibig, 2010). For example, anger was consistently linked to sympathetic activation, evidenced by increased HR, blood pressure, and respiratory activity, along with elevated electrodermal responses. Anxiety, often induced via threat-of-shock paradigms, was characterized by reciprocal sympathetic activation and vagal withdrawal - marked by shallow, rapid breathing, and elevated HR and SCL (Kreibig, 2010).

Positive emotions also revealed varied autonomic patterns (Kreibig, 2010). For example, amusement, typically elicited through comedic film clips, showed increased vagal control, heightened vascular alpha-adrenergic activity, elevated respiratory and electrodermal responses, but reduced beta-adrenergic influence on cardiac activity. Contentment, by contrast, exhibited decreased sympathetic activation and mild vagal engagement, consistent

with relaxation responses (i.e., lower HR, blood pressure, and SCL). Happiness demonstrated a complex profile involving vagal withdrawal, peripheral vasodilation, and increased electrodermal and respiratory activity, indicating a differentiated pattern of sympathetic arousal (Kreibig, 2010). Joy showed a distinctive combination of increased beta-adrenergic activity, elevated RR, and enhanced vagal control, reflecting motivational engagement. Responses to anticipatory pleasure varied by stimulus type - visual stimuli decreased HR and increased vagal control, whereas imagined stimuli evoked cardiac and respiratory activation. Pride was linked to decreased HR and increased SCL, but no changes in PEP, CO, or TPR - suggesting reduced beta-adrenergic activity and increased cholinergic influence, although findings were preliminary. Relief, similar to sadness, involved reduced sympathetic vascular and respiratory activity, coupled with distinct electrodermal deactivation (Kreibig, 2010).

These results underscore the complexity and diversity of emotional physiology, suggesting that emotional experiences are associated with nuanced and emotion-specific ANS responses (Kreibig, 2010). While negative emotions like anger and anxiety consistently displayed sympathetic dominance, positive emotions demonstrated greater variability. Notably, amusement exhibited a distinct physiological profile from happiness or joy, marked by increased HRV, decreased cardiac contractility (i.e., longer PEP), and elevated electrodermal activity (Kreibig, 2010). Amusement also involved deeper, faster breathing - likely influenced by the laughter response - while happiness was linked to shallower breathing. Moreover, TPR increased during amusement but remained stable in joy and pride. These distinctions highlight amusement's unique physiological signature, particularly in the context of humor, as opposed to the broader emotional tone of happiness (Kreibig, 2010).

Supporting these findings, Shiota et al. (2011) further explored physiological responses to enthusiasm, attachment love, nurturant love, amusement, and awe, compared to neutral states. Results revealed distinct physiological profiles across emotions (Shiota et al.,

2011). Enthusiasm was associated with increased sympathetic activation - elevated HR, SCL, mean arterial pressure (MAP), and RR. Attachment and nurturant love also showed elevated HR and RR but lacked typical sympathetic alpha-adrenergic or cholinergic markers. Amusement was primarily characterized by increased RR, while awe showed a unique profile with a lengthened PEP (indicating reduced sympathetic activity) alongside increased respiration (Shiota et al., 2011).

Taken together, these findings suggest that discrete emotions are associated with distinct patterns of ANS activity. While some emotions display clear sympathetic or parasympathetic dominance, others - particularly positive emotions - tend to show greater variability and context-dependent responses. As Kreibig (2010) noted, HR alone is insufficient to distinguish between sympathetic and parasympathetic contributions. Therefore, additional measures such as PEP and HRV are necessary to more accurately assess the underlying autonomic mechanisms. This highlights the importance of using diverse physiological measures to capture the complexity of emotional responses.

To further explore whether specific emotions reliably map onto distinct ANS patterns, Siegel et al. (2018) conducted a meta-analysis of 202 studies involving 8,443 participants. Their findings did not support a one-to-one relationship between emotions and unique physiological profiles (Siegel et al., 2018). HR - though the most commonly measured variable - did not consistently differentiate emotion categories. Instead, autonomic changes appeared to overlap across emotions, lacking specificity. The average magnitude of physiological change was modest and did not reliably align with particular emotions. These findings suggest that emotional physiology is context-sensitive and influenced by individual differences and situational variables (Siegel et al., 2018).

A more recent meta-analysis by Behnke et al. (2022) further reinforced this view, particularly in the domain of positive emotions. The study analyzed 120 studies involving

6,546 participants and identified a research gap: the majority of studies focused on amusement, with fewer addressing other emotions such as excitement, contentment, joy, pride, craving, sexual desire, attachment love, awe, nurturant love, and gratitude (Behnke et al., 2022). This narrow focus indicates a need for greater exploration of the full spectrum of positive affect.

Methodological issues were also noted. Emotion elicitation techniques primarily involved film clips, followed by picture presentations, behavioral manipulations, autobiographical recall, imagination exercises, music, and text reading (Behnke et al., 2022). While these methods provide experimental control, they may lack ecological validity, limiting the results' applicability to real-world emotional experiences. In terms of physiological measures, HR and SCL dominated, with less frequent use of RSA, RR, SBP, DBP, PEP, CO, MAP, SV, TPR, and other cardiovascular, respiratory and electrodermal measures (Behnke et al., 2022). This limited range may constrain understanding of the complexity of positive emotion physiology.

Crucially, Behnke et al. (2022) found minimal or weak autonomic reactivity across both sympathetic and parasympathetic measures during positive emotional states. These findings support theoretical models suggesting that positive emotions do not elicit SNS activation (Fredrickson & Levenson, 1998; Fredrickson et al., 2000; Fredrickson, 2013). However, a key exception involved approach motivation (Gable & Harmon-Jones, 2010; Harmon-Jones et al., 2013). High-approach emotions, such as joy and excitement, showed greater sympathetic activation (e.g., increased DBP and MAP) compared to low-approach emotions like amusement (Behnke et al., 2022). These findings suggest that motivational intensity may differentiate physiological responses.

The associations between the ANS and emotions have been the focus of longstanding research. Some perspectives propose that emotions are associated with distinct physiological

patterns (Kreibig, 2010; Shiota et al., 2011), while others argue that emotional experiences elicit shared or non-specific autonomic changes (Behnke et al., 2022; Lench et al., 2011; Siegel et al., 2018). Recent meta-analyses suggest that positive emotions typically do not generate strong or highly differentiated autonomic responses (Behnke et al., 2022; Siegel et al., 2018). This relative absence of SNS activation is believed to underlie the undoing effect, reinforcing the role of positive emotions in facilitating physiological recovery (Fredrickson, 2013). However, the lack of observed PNS activation appears to contradict the physiological mechanisms proposed by the Polyvagal Theory, which emphasizes parasympathetic regulation - particularly via the vagus nerve - as central to the experience and function of positive emotions (Porges, 2007).

Chapter 4. Framing Undoing Effect Within Health and Well-Being Research

Stress is a well-established risk factor for cardiovascular diseases, which remain the leading cause of disability and premature death in the European Region, accounting for over 42.5% of all annual deaths - equivalent to approximately 10,000 deaths per day (World Health Organization, 2024). Given the severe health implications of chronic stress, individuals frequently seek effective strategies for stress regulation. Successfully calming the physiological stress response is essential for maintaining health, as prolonged exposure to heightened arousal can lead to exhaustion and increased vulnerability to stress-related illnesses (Selye, 1946, 1950).

One promising avenue for stress regulation involves eliciting positive emotions, which - due to their unique psychophysiological characteristics - can serve as a buffer against stress (van Steenbergen et al., 2021). Positive emotions may also accelerate physiological recovery from negative emotional states, a function known as the undoing effect (Fredrickson & Levenson, 1998). Framing the undoing effect within the broader context of health and well-being research highlights its relevance and potential impact.

Evidence indicates that regularly experiencing positive emotions supports not only physical health (Pressman et al., 2019) but also mental well-being (Bleidorn et al., 2020) and interpersonal functioning (Kaczmarek et al., 2022). Positive emotional states have also been linked to improved outcomes in education and workplace settings (Lyubomirsky et al., 2005, Meneghel et al., 2016). Furthermore, positive emotions have been shown to buffer the effects of stress (Demorest, 2020; van Steenbergen et al., 2021), reduce pain by decreasing physiological reactivity to stress (Ong et al., 2015), promote cardiovascular health (Pressman et al., 2019), lower inflammation (Jones & Graham-Engeland, 2021), and reduce vulnerability to illness (Pressman & Cohen, 2005). Taken together, these findings underscore the importance of cultivating positive emotional experiences as part of comprehensive approach to stress management and the prevention of stress-related health conditions, particularly those involving cardiovascular functioning.

Positive Affect and Health

Building on this foundation, evidence from affective science consistently demonstrates a strong association between positive affect and cardiovascular health in otherwise healthy populations (Boehm & Kubzansky, 2012). Positive Psychological Well-Being - a multidimensional construct encompassing life purpose, personal growth, positive emotions, life satisfaction, happiness, and optimism - has been shown to protect against cardiovascular disease, even after accounting for traditional risk factors and psychological distress. Among these dimensions, optimism showed the most robust and consistent association with lower cardiovascular risk (Boehm & Kubzansky, 2012).

More broadly, Positive Psychological Well-Being is associated with healthier behaviors (e.g., regular physical activity, balanced diet) and more favorable physiological functioning, while showing inverse relationships with behaviors and biological processes that contribute to cardiovascular deterioration (Boehm & Kubzansky, 2012). A growing body of

research suggests that individuals who experience higher levels of positive affect tend to maintain more favorable cardiovascular profiles, including lower blood pressure, healthier lipid levels, and more optimal body mass indexes (BMIs) (Blanchflower et al., 2013).

Longitudinal findings further support this relationship, showing that positive affect predicts improved cardiovascular outcomes over time, even after accounting for demographic variables, existing health conditions, and lifestyle behaviors such as exercise (Boehm et al., 2020).

Building on the established link between affect and health outcomes, Steptoe and Wardle (2005) investigated the association between happiness and biological functioning in everyday life. Middle-aged men and women rated their happiness multiple times across both a workday and a leisure day. Biological markers - including salivary cortisol, ambulatory blood pressure, and HR - were measured repeatedly throughout each day. The researchers examined both immediate and long-term associations between happiness and these physiological responses, controlling for age, socioeconomic status, smoking habits, BMI, and psychological distress (Steptoe & Wardle, 2005).

The findings revealed that individuals who reported higher levels of happiness exhibited lower cortisol concentrations on both work and leisure days, indicating reduced stress (Steptoe & Wardle, 2005). In addition, men who reported greater happiness showed lower HR during the workday. Happier participants also demonstrated attenuated fibrinogen responses to laboratory-induced stress, suggesting a lower risk of cardiovascular disease. At a three-year follow-up, greater happiness was significantly associated with lower ambulatory SBP, independent of antihypertensive medication use and other covariates (Steptoe & Wardle, 2005). These results suggest that positive affect is linked to healthier biological functioning, including reduced hormonal markers of stress, decreased cardiovascular load, and lower inflammatory responses. Notably, these associations remained significant over time and were

independent of negative affect, emphasizing the distinct contribution of positive emotions to health outcomes. The study underscores the potential of positive affect to promote long-term physiological resilience and reduce risks associated with chronic illness (Steptoe & Wardle, 2005).

Moreover, positive affect has been linked to stronger immune function and reduced severity of illness (Cohen et al., 2003; Pressman & Cohen, 2005). Participants tracked their daily emotional experiences over a three-week period before being intentionally exposed to a common cold virus (Cohen et al., 2003). Those who reported higher levels of positive affect were significantly less likely to develop cold symptoms, even after accounting for age, sex, baseline immunity, education, and levels of negative affect (Cohen et al., 2003). These results suggest that positive affect may play a protective role in immune defense and lower vulnerability to infection. Further evidence indicates that individuals with greater positive affect tend to experience fewer physical symptoms in later life and report lower levels of pain in chronic conditions such as rheumatoid arthritis and fibromyalgia (Pressman & Cohen, 2005).

Another study in the affect-immunity domain explored the relationship between dispositional positive affect and levels of proinflammatory cytokines - specifically interleukin-6 (IL-6) - as a potential biological mechanism linking positive emotions to physical health (Stellar et al., 2015). In the first study, university students ($N = 94$) completed baseline questionnaires and provided oral mucosal transudate samples. IL-6 concentrations were measured using enzyme-linked immunosorbent assay techniques. The results indicated that higher levels of trait positive affect were associated with lower IL-6 levels, even after controlling for BMI (Stellar et al., 2015). These findings suggest that individuals with a greater natural tendency toward positive affect may exhibit lower levels of systemic inflammation (Stellar et al., 2015).

A second study replicated and extended these findings. Participants ($N = 119$) completed questionnaires at home and provided IL-6 samples during a laboratory visit, following procedures consistent with Study 1. In addition to measuring positive and negative affect, the study assessed dispositional positive affect and the Big Five personality traits. Once again, higher trait positive affect predicted lower IL-6 levels. Several specific positive emotions - such as awe, joy, contentment, and pride - were negatively associated with inflammation, with awe showing the strongest link to lower IL-6 levels. Moreover, participants who reported experiencing greater awe, wonder, and amazement on the day of the laboratory visit exhibited lower IL-6 levels, indicating a potential real-time physiological benefit (Stellar et al., 2015). Across both studies, trait positive affect was consistently associated with lower inflammation. Among the range of positive emotions examined, awe emerged as the strongest predictor, highlighting its potential role in promoting physical health and reducing inflammation (Stellar et al., 2015).

Positive affect may contribute to better health outcomes also by encouraging healthier lifestyle choices. Research has shown that individuals experiencing higher levels of positive affect are more likely to engage in regular physical activity (Boehm & Kubzansky, 2012; Kekäläinen et al., 2024). For instance, both women's own happiness and their partner's happiness predicted moderate to vigorous physical activity levels (Forster et al., 2024). Similarly, among individuals with metabolic syndrome, positive psychology intervention was associated with increased physical activity (Millstein et al., 2020).

Positive affect has also been linked to healthier eating habits (Sirois et al., 2015; Schubert & Bode, 2023) and better self-care practices, including improved sleep quality and reduced levels of stress-related hormones such as epinephrine, norepinephrine, and cortisol (Pressman & Cohen, 2005). Together, these biological and behavioral effects contribute to improved overall health and enhanced resilience to chronic diseases.

Beyond reducing disease risk, positive affect has also been associated with increased longevity. Studies indicate that optimistic individuals not only tend to live longer but are also more likely to achieve exceptional longevity (Lee et al., 2019). Similarly, higher trait positive affect has been linked to greater life expectancy (Xu & Roberts, 2010). These outcomes may stem from a combination of direct physiological advantages - such as lower stress reactivity and inflammation - and indirect effects via healthier behavioral patterns (Sabatini, 2014). Positive affect also promotes social well-being, which further supports physical health. Individuals with elevated levels of positive affect tend to experience more frequent and higher-quality social interactions. These connections provide emotional support, help reduce stress, and encourage the adoption of healthy behaviors (Pressman & Cohen, 2005). In turn, robust social networks have been consistently associated with lower risks of illness and premature mortality (Pressman & Cohen, 2005).

Positive Emotions and Well-Being

Positive emotions play a fundamental role in supporting overall well-being (Seligman, 2011). Research consistently shows that happier individuals tend to experience more positive than negative emotions, recall a greater number of positive life events, engage more often in social interactions, enjoy higher-quality relationships, and exhibit lower levels of psychological distress (Diener & Seligman, 2002). However, well-being does not require constant joy; rather, it involves maintaining a predominantly positive emotional state, cultivating meaningful social connections, and effectively managing stress (Diener & Seligman, 2002).

Happiness strengthens social bonds, as happier individuals tend to form high-quality relationships (Diener & Seligman, 2002) and report greater marital satisfaction (Lyubomirsky et al., 2005). Positive emotions foster favorable attitudes toward others, thereby enhancing overall relationship quality (Lyubomirsky et al., 2005). In romantic partnerships, positive

emotions are linked to relationship satisfaction (Samios & Khatri, 2019), intimacy (Horn et al., 2019; Mehta et al., 2016), commitment (Gable et al., 2006), and supportive dyadic coping (Rusu et al., 2018). They also promote cooperation and bonding between partners (Sels, 2021) and contribute to a stronger sense of self-other overlap, facilitating mutual understanding (Waugh & Fredrickson, 2006). Couples who frequently share positive emotions in response to daily experiences report higher levels of couple identity, commitment, enthusiasm, satisfaction, love, and long-term relationship quality (Gable et al., 2006; Kaczmarek et al., 2022; Kaczmarek, Kelso et al., 2022; Pagani et al., 2020). Moreover, on days when individuals report more positive emotions, they also experience greater intimacy with their partners (Rusu et al., 2022).

Positive psychology interventions highlight the critical role of positive emotions in promoting well-being. Practices such as gratitude exercises and acts of kindness have been shown to yield substantial emotional and physical health benefits (Lyubomirsky & Layous, 2013; Kaczmarek & Sęk, 2016). One such intervention, the Best Possible Self exercise, encourages individuals to envision and articulate their ideal future, resulting not only in increased positive affect but also in enhanced self-regulation, as reflected in higher cardiac vagal activity - a physiological marker of emotion regulation (Sayis et al., 2023).

Similarly, interventions grounded in the PERMA Model of Well-Being (Seligman, 2011) - which emphasizes Positive Emotions, Engagement, Relations, Meaning and Achievement - have been shown to increase happiness and reduce depressive symptoms (Gander et al., 2016). Among individuals with chronic health conditions such as heart disease, cultivating positive emotions has been associated with improved psychological well-being and better physical health outcomes (Huffman et al., 2016). Additionally, positive emotions have been found to buffer against stress (Demorest, 2020; van Steenbergen et al., 2020), supporting more effective affect regulation when facing everyday challenges. Taken together,

these findings suggest that cultivating positive emotions is a valuable strategy for enhancing resilience, improving stress management, and promoting long-term well-being.

Daily emotional processes and their relationship to psychological resilience were explored in a longitudinal study examining how individuals experience and recover from stress (Ong, 2006). Over a 45-day period, participants ($N = 27$) reported their emotional states, identified their most stressful daily event, and rated its perceived intensity. A baseline measure of trait psychological resilience was also collected (Ong, 2006).

The findings revealed that higher stress levels were associated with lower positive emotions and higher negative emotions (Ong, 2006). While daily stress consistently led to increased negative emotions, positive emotions served as a buffer, mitigating the stress impact. Specifically, stress diminished positive emotions and hindered recovery, whereas maintaining positive emotions enhanced resilience and facilitated recovery (Ong, 2006). Notably, individuals with higher resilience not only sustained positive emotions under stress but also used them as psychological resources to recover more effectively from adverse experiences (Ong, 2006). These results were replicated and further extended in a study on emotion regulation among widows following spousal loss. Greater daily positive emotions were linked to lower stress and reduced negative emotions, reinforcing the buffering role of positive emotions (Ong, 2006).

These findings are consistent with prior research (Fredrickson & Levenson, 1998; Fredrickson et al., 2000), which has shown that positive emotions facilitate recovery from stress. Under stressful conditions, positive emotions help replenish personal resources, thereby fostering resilience (Fredrickson & Levenson, 1998; Fredrickson, 2013). Thus, this study provides compelling empirical support for the Broaden-and-Build theory, highlighting the central role of positive emotions in adaptive stress regulation and emotional recovery (Fredrickson, 2013).

Drawing on a longitudinal dataset comprising 463 participants and 1,898 observations, Sewart et al. (2019) investigated whether positive affect buffers symptom severity in individuals with social anxiety disorder, major depressive disorder, and generalized anxiety disorder. On average, participants reported mild to moderate levels of both interpersonal and non-interpersonal stress. The prevalence of clinically significant generalized anxiety disorder (1.8%), social anxiety disorder (3.3%), and major depressive disorder (2.8%) was consistent with rates observed in broader adolescent and young adult populations (Sewart et al., 2019).

The findings revealed that positive affect significantly attenuated the impact of chronic interpersonal stress on symptom severity in social anxiety disorder and major depressive disorder. This buffering effect, however, was not observed in cases of generalized anxiety disorder (Sewart et al., 2019). Furthermore, positive affect did not mitigate the effects of chronic non-interpersonal stress across any of the disorders studied. Notably, higher positive affect also reduced the influence of negative affect on subsequent symptom severity (Sewart et al., 2019).

These results support the Broaden-and-Build Theory (Fredrickson, 2013), which suggests that positive emotions contribute to the development of personal resources and facilitate recovery from negative emotional states. Collectively, the findings underscore the protective function of positive affect, particularly in buffering the effects of chronic interpersonal stress in social anxiety and major depressive disorders. Enhancing positive affect may therefore serve as an effective strategy for reducing psychological distress in these contexts (Sewart et al., 2019).

Further support for the buffering role of positive emotions comes from a study examining how daily positive experiences mitigate the effects of stress on well-being (Nezlek et al., 2017). Over a two-week period, participants ($N = 131$) submitted daily reports via a website, assessing their well-being - including affect, self-esteem, depressogenic adjustment,

worry, and rumination. In addition, they rated daily events in terms of stressfulness, positivity, importance, and mindfulness. The findings revealed that well-being was consistently higher on days with lower stress and greater positive experiences. Importantly, positive daily experiences buffered the adverse effects of stress on self-esteem, worry, rumination, and negative affect. These results underscore the role of daily positive experiences in shaping emotional resilience and overall well-being, particularly in the context of daily stressors (Nezlek et al., 2017).

Using the Day Reconstruction Method, Catalino and Fredrickson (2011) investigated the emotional and cognitive processes that foster flourishing - a state of optimal mental well-being - by examining how individuals respond to daily positive experiences. Compared to non-flourishers and individuals experiencing depression, flourishers exhibited greater positive emotional reactivity to everyday pleasant activities, such as helping others, social interactions, play, learning, and spiritual engagement. For instance, flourishers experienced more than twice the emotional boost from engaging in prosocial behaviors compared to non-flourishers and depressed individuals. Over time, this heightened positive emotional responsiveness predicted higher mindfulness levels, particularly two key dimensions: observing (noticing and attending to present experiences) and nonreactivity to inner experience (experiencing thoughts and emotions without being overwhelmed) (Catalino & Fredrickson 2011).

These findings align with Fredrickson's Broaden-and-Build Theory (Fredrickson, 2013; Fredrickson & Levenson, 1998), which posits that positive emotions help individuals accumulate enduring personal resources. In this context, positive emotional reactivity promoted mindfulness, a cognitive resource strongly linked to better psychological functioning (Catalino & Fredrickson 2011). Further analysis showed that increases in mindfulness were significantly associated with improvements in flourishing over time. This suggests that flourishers maintain and amplify their well-being through a positive feedback

loop: (a) they experience stronger positive emotional responses to daily activities; (b) these emotional experiences promote mindfulness, enhancing cognitive resources for emotion regulation; and (c) greater mindfulness, in turn, supports continued flourishing and optimal mental health. Overall, this study offers empirical support for the psychological mechanisms underlying flourishing, emphasizing the role of positive emotional reactivity in the development of mindfulness and the promotion of long-term well-being (Catalino & Fredrickson 2011).

In summary, a growing body of evidence supports the beneficial role of positive emotions in promoting health outcomes. Positive affect has been linked to enhanced immune function (Jones & Graham-Engeland, 2021; Stellar et al., 2015), improved cardiovascular health (Boehm & Kubzansky, 2012; Pressman et al., 2019), healthier lifestyle behaviors (Kekäläinen et al., 2024; Sirois et al., 2015; Schubert & Bode, 2023), and increased longevity (Lee et al., 2019). These benefits arise through both direct physiological mechanisms - such as reduced stress hormone levels and enhanced immune responses - and indirect pathways, including more adaptive health behaviors and stronger social relationships (Sabatini, 2014). As such, cultivating positive emotions represent an effective strategy for public health interventions aimed at enhancing well-being and preventing illness.

Furthermore, positive emotions contribute significantly to psychological well-being by fostering greater life satisfaction, emotional stability, and overall mental health (Fredrickson, 2013). They strengthen social bonds (Diener & Seligman, 2002; Lyubomirsky et al., 2005), buffer the effects of stress (Demorest, 2020; van Steenbergen et al., 2020), and support resilience by facilitating faster recovery from adversity (Fredrickson, 2013; Ong, 2006). Collectively, these findings underscore the central role of positive emotions in maintaining both physical and mental health, framing the undoing effect within the broader context of health and well-being research.

Chapter 5. Esports as an Emotional and Physiological Context for Affective Research

Esports refers to competitive or recreational video gaming that promotes both professional development and personal growth among players (Pedraza et al., 2020). Unlike casual gaming, esports is defined by its structured competitive environments, including ranking systems, formal tournaments, and professional leagues, where individuals or teams compete in high-stakes settings. This dynamic ecosystem has experienced exponential growth in recent years, with estimates suggesting that over 3 billion people worldwide engage in gaming, and a global esports audience exceeding 320 million viewers as of 2025 (Statista, 2025). The esports industry continues to expand rapidly, attracting sponsorships, investments, and academic interest due to its increasing cultural and economic relevance.

Performance in esports is a multifaceted construct, encompassing both goal-oriented success (e.g., winning matches) and the refinement of in-game skills (Pedraza et al., 2020). Competitive players must master a combination of perceptual, cognitive, and motor skills, including rapid decision-making, sustained attention, and precise hand-eye coordination (Raab et al., 2015; Voss et al., 2010). The concept of mechanical expertise (Donaldson, 2017) captures the complex interaction between strategic thinking, technical execution, and adaptive gameplay, highlighting esports as a cognitively demanding performance domain.

As in traditional sports, emotions play a central role in esports performance (Beres et al., 2023). Research demonstrates that positive emotions (e.g., excitement and enthusiasm) can enhance performance (Behnke, Gross et al., 2022). Esports players must operate in high-pressure environments where split-second decisions can determine the outcome of a match, and momentary emotional disruptions may hinder performance. Thus, the ability to regulate emotions is crucial for achieving competitive success (Nicholls & Polman, 2007; Nagorsky & Wiemeyer, 2020).

Recent findings indicate that esports players experience stressors and emotional challenges similar to those experienced by traditional athletes (Leis et al., 2021; Leis & Lautenbach, 2020; Smith et al., 2019). These include performance pressure, competitive anxiety, and interpersonal challenges within teams (Himmelstein et al., 2017). In response, esports players employ a range of coping strategies, including problem-focused coping (e.g., goal setting, adapting strategies), emotion-focused coping (e.g., relaxation, mindfulness), and avoidance coping (e.g., psychological distancing) (Poulus et al., 2020, 2022a; Smith et al., 2019).

However, esports also introduces unique challenges not typically encountered in traditional sports (Leis et al., 2021; Leis & Lautenbach, 2020; Smith et al., 2019). These include game-specific stressors such as rapidly evolving gameplay mechanics (e.g., shifts in gameplay strategies; Kou & Gui, 2020), technical failures (e.g., disconnections; Poulus et al., 2022a), and tightly compressed competitive schedules that limit recovery time (Mateo-Orcajada et al., 2022). Additionally, the digital nature of esports - particularly the anonymity of online interactions - can give rise to online toxicity and negative social encounters, adding further emotional strain (Beres et al., 2023; Himmelstein et al., 2017; Suler, 2004). The high cognitive and emotional load required in many team-based, strategic esports titles further underscores the importance of psychophysiological recovery under time constraints.

Among esports titles, Counter-Strike 2 (CS2) stands out as a particularly rich environment for studying emotional and physiological processes. Its highly competitive format, emotionally intense in-game events (Behnke et al., 2021), and capacity to evoke strong physiological arousal (Behnke et al., 2024) make it especially relevant for affective research. As a first-person tactical game, CS2 demands real-time decision-making, fine motor control, and strategic coordination. The round-based structure and elimination format produce

frequent emotional fluctuations, ranging from the elation of a clutch win to the frustration of a game-losing mistake.

Esports provides a unique, controllable, and ecologically valid environment for studying emotions in high-performance contexts. Physiological studies confirm that high-stakes esports environments like CS2 evoke robust ANS responses, including elevated HR, reflecting heightened psychophysiological engagement (Behnke et al., 2024; Sadowska et al., 2023). The unpredictable nature of gameplay - including sudden ambushes, tactical plays, and pressure-laden finales - offers an ideal context for investigating real-time emotional and physiological dynamics in performance settings. Moreover, the stationary nature of gameplay minimizes motion artifacts, enabling continuous and accurate physiological monitoring - such as cardiac activity, electrodermal activity, and facial expression analysis - during emotionally charged moments.

This chapter explores why esports, and particularly CS2, represents a promising avenue for research on stress, emotion, and performance. By integrating existing evidence, it highlights how this competitive platform can inform our understanding of affective processes in dynamic, real-world settings while offering methodological advantages for experimental emotion research.

Evidence for Emotional and Physiological Responses in Esports

To better understand the emotional experiences of gamers, Behnke et al. (2021) investigated scenarios that elicited specific positive and negative emotions in Counter-Strike: Global Offensive (CS:GO). A total of 652 players participated in the study. They were divided into four groups and asked to recall and describe a specific moment during gameplay when they experienced one of four target emotions: enthusiasm, amusement, sadness, or anger. Participants provided written descriptions of these events, focusing on the emotions they experienced during gameplay (Behnke et al., 2021).

To analyze the emotional contexts, two independent raters conducted open coding on the descriptions, identifying keywords that summarized the events (e.g., “clutch,” “hacking,” “victory,” or “team sabotage”) (Behnke et al., 2021). Broader thematic categories (e.g., “successful performance,” “negative team behavior,” “communication issues”) were then derived based on conceptual similarities. Emotional language within the narratives was analyzed using the Linguistic Inquiry and Word Count tool, which quantifies linguistic and affective features of written text (Behnke et al., 2021).

Players’ descriptions varied in length and were clustered into 12 broader categories encompassing 87 unique scenarios (Behnke et al., 2021). Amusing situations were often associated with performance context, humorous events, positive performance outcomes, successful performance, and instances of underperformance. Gamers mentioned winning matches, executing skillful kills, playing with friends, or performing ridiculous shots. Enthusiastic scenarios frequently involved successful performance, favorable outcomes, competitive contexts, and positive team dynamics. Gamers recalled clutch plays (i.e., winning a round after being the last player alive on the team), victories, and competitive matches (Behnke et al., 2021).

Anger was primarily triggered by negative behaviors from teammates, unfavorable performance outcomes, misconduct by opposing players, communication issues, underperformance, and technical difficulties (Behnke et al., 2021). Gamers described situations such as playing with weak teammates, encountering hackers (e.g., cheating, trolling, smurfing), experiencing team sabotage, internet lag, losing matches, or teammates deliberately throwing the game. Sad scenarios often involved negative performance outcomes, underperformance, teammate misconduct, poor behavior from opponents, and communication breakdowns. Gamers mentioned losing, playing with weak teammates, losing matches they felt should have been won, and underperforming (Behnke et al., 2021).

The findings illustrate that specific in-game scenarios consistently evoke distinct emotional responses. Positive emotions in esports emerge from successful performance outcomes, personal skill expression, and competitive achievements. For instance, unexpected or skillful plays (e.g., improbable shots) often evoke amusement, while high-pressure moments (e.g., clutch plays) trigger enthusiasm. In contrast, negative emotions stem from unsatisfactory performance, team dysfunction, or perceived unfairness during gameplay. For instance, frustration with teammates leads to anger, whereas losses and setbacks - especially those perceived as undeserved - can lead to sadness (Behnke et al., 2021).

The emotional aspects of esports were further investigated by Shin et al. (2012). Participants underwent electroencephalography (EEG) recordings to measure frontal asymmetry indices before, during, and after gameplay. To isolate emotion-specific effects, the study included baseline and control conditions such as sitting idle, hearing game sounds, and watching gameplay without active participation. Each participant played 10 rounds of Counter-Strike in a controlled offline setting. Emotional responses to two key in-game events - "shooting" (eliminating an opponent) and "being shot" (being eliminated) - were analyzed. Self-reported emotional ratings (e.g., happiness, anger, arousal) were collected pre-game, during gameplay, and post-game (Shin et al., 2012).

The results revealed that watching gameplay passively (screen condition) elicited negative emotions, as indicated by greater right-frontal activation (Shin et al., 2012). In contrast, actively playing and successfully eliminating opponents (shooting events) elicited positive emotions, demonstrated by increased left-frontal activation following the event. Being eliminated induced negative affect, reflected in increased right-frontal activation. Participants reported significantly higher levels of happiness during and after gameplay compared to pre-game period. Anger and arousal were most prominent during gameplay relative to both pre- and post-game phases. Overall, the findings suggest that Counter-Strike

elicits both positive and negative emotional responses, as supported by EEG and self-report data (Shin et al., 2012).

These results align with broader research in affective gaming research, which consistently show that positive affect - such as enthusiasm, happiness, pride, and vigor - are associated with better performance outcomes (Behnke, Gross et al., 2022; Kou & Gui, 2020; Mateo-Orcajada et al., 2022), accomplishing in-game goals (Mateo-Orcajada et al., 2022), and maintaining cooperative team dynamics (Poulus et al., 2022b). Conversely, negative affect - such as frustration, anger, and tilt - are linked to losing matches (Kou & Gui, 2020; Mateo-Orcajada et al., 2022) and to team communication breakdowns or underperformance (Kou & Gui, 2020; Poulus et al., 2022a).

To better understand stress among esports players, Schulze et al. (2021) conducted a systematic review to categorize well-being risks into biological, psychological, and social domains. Drawing on 21 studies, the review identified key stressors in each category (Schulze et al., 2021). Biological risks included (a) musculoskeletal injuries (e.g., wrist, neck, and back pain) due to repetitive fine motor movements and prolonged gaming sessions; (b) sleep disturbances due to late-night gaming and screen exposure; (c) poor dietary habits; (d) excessive caffeine use; and (e) elevated physiological arousal resembling traditional sports stress responses (Schulze et al., 2021). Psychological risks encompassed (a) high competitive stress; (b) cognitive fatigue; (c) gaming addiction; and (d) depression linked to poor coping strategies and both adaptive and maladaptive stress management techniques (Schulze et al., 2021). Social risks involved (a) exposure to online harassment; (b) gender-based discrimination (particularly women); and (c) racism within the esports community (Schulze et al., 2021). The review draws attention to the range of risks esports players face and underscores the need for tailored interventions to address these challenges. Biological risks - such as repetitive strain injuries and sleep disturbances - require ongoing physical health

monitoring (Schulze et al., 2021). Psychological stress and gaming addiction call for comprehensive mental health support, while social risks, including harassment and discrimination, demand community-driven solutions (Schulze et al., 2021). The study advocates for preventive measures such as educational programs, health guidelines, and further research into esports-specific risks to enhance players' well-being (Schulze et al., 2021).

The competitive and high-pressure environment of esports closely parallels that of traditional sports, requiring mental resilience, adaptive coping strategies, and effective stress regulation (Leis & Lautenbach, 2020). Research has identified a wide range of stressors, physiological and emotional responses, and coping mechanisms among professional esports athletes, highlighting the significant psychological demands of the field (Leis et al., 2021). Professional esports players report numerous stressors, including performance expectations, self-evaluation, team dynamics, audience pressure, social media scrutiny, and environmental constraints (Leis et al., 2021). Players consistently reported self-imposed expectations as a primary source of stress - particularly the pressure to win, perform flawlessly, and meet personal or team goals. Some reported internal pressure as their greatest challenge, while others struggled with maintaining focus during matches. Fear of failure and its emotional consequences also emerged as key stressors, especially when facing stronger or more experienced opponents. Losing a game, facing strong opponents, or perceiving an opposing team as superior further intensified these stressors (Leis et al., 2021). Interpersonal relationships within teams significantly influenced stress levels. A lack of confidence in teammates often led players to feel an increased individual pressure to compensate. Additionally, intra-team criticism - such as blame or questioning of performance - contributed to elevated anxiety and pressure (Leis et al., 2021). Spectator presence, both online and in-person, evoked mixed reactions. While some players found crowd support motivating, others

experienced heightened anxiety due to performance expectations. Social media also emerged as a double-edged sword; while negative comments intensified self-doubt, a few players reported using the pressure as motivation for self-improvement (Leis et al., 2021). External factors such as travel, jetlag, and limited preparation time added to the psychological burden. Offline tournaments in foreign locations were physically exhausting for some, while others found online events more nerve-wracking. Organizational shortcomings, including poor coaching or inadequate team management, further exacerbated stress (Leis et al., 2021).

Professional esports players experience a range of emotional and physiological reactions before, during, and after competition (Leis et al., 2021). Before competing, players frequently reported anxiety, nervousness, excitement, sweating, shaking, stuttering, tunnel vision, and elevated HR. These symptoms were most intense immediately prior to gameplay and typically subsided once the match began (Leis et al., 2021). During gameplay, players rarely reported stress responses, likely due to their intense focus on the game and task-relevant information. Given the limited capacity of working memory (Fougnie, 2008), focusing on gameplay may naturally suppress awareness of physiological stress symptoms (Leis et al., 2021). Emotional responses following competition were strongly influenced by performance outcomes. Victory elicited happiness, excitement, and satisfaction, whereas defeat was associated with anger, sadness, disappointment, and frustration. Players' subjective impact on the game outcome also shaped their emotional reactions (Leis et al., 2021).

Professional esports players employ a range of coping strategies to manage stress and optimize performance across all phases of competition (Leis et al., 2021). Communication with teammates was the most commonly used strategy before competition. Players engaged in discussions about game plans, expectations, and mental preparation, which helped reduce pre-match anxiety (Leis et al., 2021). Focusing on in-game performance emerged as the primary strategy during competition. This approach helped players stay engaged and suppress stress-

related symptoms. Similar strategies were observed in traditional sports such as rugby (Nicholls et al., 2006, 2009), golf (Nicholls et al., 2010), and tennis (Swettenham et al., 2020). Some esports players also adopted avoidance-based coping strategies, such as reducing skillful but risky actions under pressure - a pattern also observed among CS:GO players (Smith et al., 2019). After competition, communication remained essential. Players often debriefed with teammates, discussing their performance, analyzing mistakes, and receiving constructive feedback (Leis et al., 2021).

While earlier studies have examined stress in esports more broadly, this study specifically investigates the stressors and coping strategies experienced by elite Counter-Strike players in high-pressure competitive contexts (Smith et al., 2019). Using a qualitative approach, the researchers conducted semi-structured interviews with seven male players from teams competing in the ESL Premiership CS:GO Spring Finals, a premier esports competition in the United Kingdom. Data were collected through Skype interviews, conducted one to three weeks after the competition. Thematic analysis was employed to identify key stressors and coping mechanisms, with stressors classified as either internal (e.g., team dynamics) or external (e.g., audience scrutiny) (Smith et al., 2019).

Internal stressors included team and individual issues. Gamers described poor in-game communication, critical feedback from team leaders, lack of confidence in teammates, and interpersonal conflicts (Smith et al., 2019). Some struggled with aggressive communication styles, teammates failing to follow instructions, or differences in attitude and approach to practice or competition. Gamers also described difficulties balancing esports with personal responsibilities (e.g., school or employment), and reported that irregular sleep patterns and demanding travel schedules posed additional challenges. (Smith et al., 2019).

External stressors included social media criticism and audience pressure. Gamers faced online scrutiny, particularly on platforms like Twitter, where negative feedback often

targeted individual performance or called for changes to team lineups (Smith et al., 2019).

Gamers reported that last-minute adjustments to competition schedules and inadequate time for warm-up activities contributed additional stress. Also, performing in front of live audiences and receiving immediate feedback intensified performance-related anxiety (Smith et al., 2019).

To manage these stressors, gamers employed a range of coping strategies, including (a) emotion-focused coping, such as listening to music, taking breaks, or mentally disengaging to regulate emotional responses; (b) problem-focused coping, including post-match team discussions aimed at resolving conflicts and improving gameplay strategies; (c) avoidance coping, which involved disregarding criticism during gameplay; (d) approach coping, such as organizing team boot camps and assigning specific roles to enhance team cohesion and reduce pressure; and (e) appraisal-focused coping, where players reframed criticism or reanalyze performance statistics to reduce emotional strain and focus on personal development. Despite the presence of these constructive strategies, some players also reported engaging in maladaptive behaviors, including smoking or venting frustration (Smith et al., 2019).

Experimental Insights into Stress and Emotion in Esports

Building on the established link between stress and SNS activation, this study investigated the physiological stress responses of players during a CS:GO tournament (Sadowska et al., 2023). The researchers aimed to assess how acute stress during gameplay manifested across cardiovascular, hormonal, and biochemical markers (Sadowska et al., 2023). A central goal was to determine whether these physiological responses differed between players who won and those who lost. The study involved twenty male participants, each of whom competed in two individual matches within a single-day CS:GO tournament setting (Sadowska et al., 2023).

The tournament consisted of two stages. In the first stage, players were randomly paired for matches, while in the second stage, winners and losers from the initial round were paired again. Each match lasted between 4 and 7 minutes and was played to 16 frags (kills). Physiological data were collected at multiple time points: before, during and after the match. Continuous measures included HR, SBP and DBP. Blood samples were also collected to assess levels of cortisol, testosterone, and blood lactate (Sadowska et al., 2023).

The results indicated that participating in a CS:GO tournament evoked significant physiological arousal (Sadowska et al., 2023). HR increased significantly during gameplay, with a mean maximum HR of 128 bpm; however, no significant differences were found between winners and losers. A HRV decrease was observed in all players, further confirming the stress-inducing nature of the tournament. SBP significantly increased after matches, while DBP remained unchanged. Cortisol levels increased significantly across all participants, reinforcing the interpretation of gameplay as a psychological stressor. No changes in testosterone levels were detected, and blood lactate levels remained stable, indicating a lack of significant physical exertion. Physiological and hormonal responses did not differ between winners and losers, suggesting that stress responses were similar regardless of match outcome (Sadowska et al., 2023). This study confirmed that participation in CS:GO tournaments serves as an acute stressor, eliciting clear physiological arousal characterized by increased HR, elevated SBP, heightened cortisol levels, and reduced HRV. Notably, these stress responses were consistent among players, regardless of whether they won or lost. The findings underscore the ability of esports competitions - particularly fast-paced first-person shooter games - to induce physiological stress reactions similar to those found in traditional high-intensity sports settings (Sadowska et al., 2023).

To better understand stress responses in esports, this study examined the phenomenon of choking under pressure among professional CS:GO players (Naidenova et al., 2024). The

primary objectives were to determine whether esports players experience performance declines in high-pressure situations and to assess whether these effects differ between online and live (LAN) tournaments. The study analyzed match-level data from CS:GO tournaments to assess the impact of high-pressure scenarios, such as overtime rounds, on player performance (measured via player rating). At the round-level analysis, individual skill was assessed using headshot percentage, while team coordination was evaluated using teammate damage frequency (Naidenova et al., 2024).

The match-level analysis revealed that players' overall performance declined under pressure, with an approximate 2% reduction in player ratings during overtime rounds (Naidenova et al., 2024). However, the format of the tournament significantly moderated this effect. The negative impact of pressure was reduced by half in online tournaments compared to LAN - likely due to the absence of a physical audience and the generally lower competitive intensity in online formats (Naidenova et al., 2024). At the round level, headshot accuracy significantly declined in overtime rounds, reflecting a decrease in individual performance, while teammate damage increased, suggesting impaired team coordination under pressure. The rise in teammate damage was less pronounced in online tournaments, indicating that coordination difficulties were more prominent in LAN settings (Naidenova et al., 2024). The study provides compelling evidence for choking under pressure in esports, demonstrating that both individual and team performance deteriorate during high-stakes moments, such as overtime rounds. The findings also underscore the influence of tournament format, with online settings providing a buffer against performance pressure - likely due to reduced audience presence and lower competitive intensity (Naidenova et al., 2024).

Grounded in the Biopsychosocial Model (Blascovich, 2008), this study investigated how challenge and threat evaluations influence gaming performance and whether these evaluations are shaped by performance-related feedback (Behnke et al., 2020). CS:GO players

($N = 82$) were randomly assigned to either a social challenge or social threat condition. These evaluations were manipulated using performance-related feedback: participants in the challenge condition were told they outperformed 83% of other players, fostering a sense of competence, while those in the threat condition were told they performed worse than 83% of other players, fostering a sense of incompetence (Behnke et al., 2020).

After providing informed consent, participants were fitted with cardiovascular sensors (Behnke et al., 2020). They completed demographic questionnaires, a 5-minute resting baseline, and a 10-minute warm-up. Participants then engaged in two rounds of competitive gameplay, separated by 2-minute recovery intervals. Following the first match, they received the manipulated performance feedback and completed a re-evaluation of challenge and threat appraisals. Upon completing the second match, participants were debriefed and rewarded with cinema vouchers, with additional prizes awarded to tournament winners (Behnke et al., 2020).

Key findings revealed that positive performance feedback enhanced challenge appraisals, whereas negative performance feedback diminished them (Behnke et al., 2020). However, the feedback itself did not directly influence physiological responses or performance outcomes. Instead, performance in Match 2 appeared to be shaped by players' initial performance and appraisals (Behnke et al., 2020). Gamers who entered the competition with greater confidence and physiological readiness performed better overall (Behnke et al., 2020). More experienced gamers were more likely to appraise the competition as a challenge - that is, they perceived their personal resources as exceeding the demands of the situation - which predicted better performance across both matches (Behnke et al., 2020). Furthermore, increased HR was linked to task engagement and better performance, indicating that physiological arousal reflected psychophysiological readiness for action rather than stress-related disruption (Behnke et al., 2020).

Previous research has highlighted the adaptive role of physiological arousal in esports performance (Behnke et al., 2020). Building on this, adopting a mindset that interprets arousal as beneficial may enhance resilience and improve performance in high-pressure competitive settings. To further investigate the role of mindset (Crum et al., 2013, 2017; Dweck, 2006) and emotion regulation (Gross, 2015) in esports, the present study implemented a Synergistic Mindsets Intervention (SMI). This approach aimed to optimize stress responses and improve performance outcomes in an esports context (Behnke et al., 2024). The SMI is based on two core principles (a) situation reappraisal, which involves framing stress-inducing events as challenges and opportunities for growth; and (b) response reappraisal, which encourages interpreting physiological responses - such as a racing heart - as performance-enhancing (Yeager et al., 2022). By integrating both principles, the intervention promotes a more adaptive and positive mindset. Prior research has shown that challenge responses, characterized by positive affect and efficient cardiovascular functioning, are associated with better performance (Behnke & Kaczmarek, 2018; Hase et al., 2025), making SMI a promising regulatory tool for esports players (Behnke et al., 2024).

CS:GO players ($N = 300$) participated in the largest esports experiment to date (Behnke et al., 2024) and were randomly assigned to either the SMI or a control group receiving a neutral brain-facts intervention. The experiment was conducted in three stages: baseline, training, and tournament. Participants visited the lab, completed self-report questionnaires, played an initial CS:GO match to establish baseline performance and physiological markers, and receive their assigned intervention. Over two weeks, participants applied either the SMI or control intervention during daily gaming sessions, documenting their adherence and experiences through the study application. Following training stage, participants competed in a cash-prize esports tournament while their affective and

physiological responses were continuously monitored. A follow-up assessment was conducted one month later (Behnke et al., 2024).

The SMI was well received by gamers and led to more adaptive stress mindsets, more positive evaluations of the tournament, and greater use of reappraisal strategies for emotion regulation (Behnke et al., 2024). However, contrary to expectations, the intervention did not yield significant improvements in affective responses or tournament performance compared to the control condition (Behnke et al., 2024). The authors suggest that the inherently positive nature of high-stakes esports competitions for many players may have limited the potential for the intervention to produce additional benefits (Behnke et al., 2024).

Counter-Strike 2 as Context for Studying the Undoing Effect

CS2 - the latest installment in Valve Corporation's iconic franchise - is among the most psychologically and mechanically demanding esports titles. With its tactical, round-based structure and a competitive mode that mirrors professional play, CS2 demands quick reflexes, strategic execution, and effective team coordination. The game attracts over 1.8 million daily active players (Steam, 2025) and engages a vibrant professional scene, including elite tournaments such as the Electronic Sports League (ESL) Pro League and the Counter-Strike Majors. For example, the 2024 Professional Gamers League (PGL) Major Copenhagen drew more than 1.8 million live viewers (Šimić, 2024), highlighting the game's global popularity and emotional intensity.

Uniquely, CS2 bridges the gap between casual and professional play (Rambusch et al., 2007; Schultze et al., 2021). Its ranked matchmaking system exposes non-professional players to high-stakes competition, mirroring the pressure of elite esports (Rambusch et al., 2007). As a motivated performance context, esports aligns with the Biopsychosocial Model of Challenge and Threat (Blascovich, 2008). When players pursue goals such as winning or ranking up, they appraise whether their cognitive, motor, and physiological resources are sufficient to

meet the demands of competition. A challenge state (i.e., perceived resource sufficiency) promotes cardiovascular and performance efficiency, while a threat state (i.e., perceived resource insufficiency) leads to physiological inefficiency, even with similar effort (Seery, 2013). By providing a scalable environment that encompasses both casual and elite levels of competition, CS2 allows researchers to investigate the real-time interplay between stress, emotions, and performance, offering valuable insights into the science of emotion and performance

The game's fast-paced action, unpredictable scenarios, and real-time team dynamics make CS2 a valuable environment for studying emotional and physiological responses in performance contexts. Research has shown that CS2 evokes heightened autonomic arousal (Behnke et al., 2024), strong emotional reactions (Behnke et al., 2021), and game-related pressure (Sharpe et al., 2024). Moreover, the digital nature of esports allows researchers to conduct real-time physiological monitoring - such as cardiac activity, electrodermal activity, and facial expression analysis - without interference from physical movement, making it especially well-suited for affective science. Esports offers an ecologically valid, emotionally intense, personally meaningful, and behaviorally engaging context for investigating how emotions and stress influence performance and recovery. Competitive gameplay evokes strong emotional and physiological responses (Behnke et al., 2021, 2022, 2024), making it a compelling setting to test the undoing effect in a real-world performance context.

Chapter 6. Methods

The aim of the present study was to examine the influence of positive emotions on physiological recovery following esports performance. Participants played CS2, one of the leading esports titles, with 1,818,368 active players reported in April 2025 (Steam, 2025). Emotional states were elicited using film clips. Each participant completed a single 10-minute match, followed by the induction of either an amusement or neutral emotional state. Esports

performance was framed as a real-life tournament scenario, utilizing validated research protocols (Behnke et al., 2024) to enhance the intensity of stress and emotional engagement. Physiological responses were measured continuously throughout the study. It was hypothesized that positive emotions would optimize cardiovascular recovery, both in terms of speed (i.e., gamers recovered faster) and depth (i.e., gamers displayed greater reduction in cardiovascular activation).

This is the first study to test physiological recovery within esports, using esports performance as a naturalistic emotional stimulus and continuous physiological monitoring to capture subtle cardiovascular changes. To assess recovery processes, this study employed ICG, which enabled detailed measurement of SNS activity. In addition, a multiverse analysis was used to explore if results were influenced by both variables operationalization and analytical strategy. This integrative approach aimed to provide a more nuanced understanding of psychophysiological recovery ultimately contributing to the theoretical development of the undoing effect.

Previous studies investigating the undoing effect - the idea that positive emotions can accelerate recovery from stress (Fredrickson & Levenson, 1998) - have primarily relied on passive tasks to elicit emotions, such as viewing images (Behnke et al., 2023). While methodologically convenient, such approaches often lack emotional intensity and ecological validity. In real-life scenarios, emotional experiences are more vivid, personally meaningful, and accompanied by heightened physiological arousal. Therefore, to advance our understanding of the undoing effect, it is essential to examine it in settings that better reflect natural emotional dynamics.

Competitive gaming offers an ideal platform for this kind of research. Esports environments combine intense psychological engagement (Behnke et al., 2021), elevated physiological activation (Behnke et al., 2022, 2024), and controlled experimental conditions.

It enables researchers to track emotional and physiological responses with precision. Gamers are highly motivated and psychophysiologicaly invested in gameplay, which often involves time pressure, high stakes, and team dynamics (Pedraza et al., 2020). At the same time, they remain seated, minimizing movement-related interference in physiological recordings. These characteristics make esports an ecologically valid and methodologically feasible setting to investigate emotional processes, especially those linked to stress and recovery.

Research Questions and Main Hypotheses

The present study examined whether inducing positive emotions following an esports performance would optimize cardiovascular recovery (Research Question 1). It was hypothesized that:

- H1a: Gamers who experience positive emotions after a stressful match will exhibit faster recovery compared to those in a neutral emotional state.
- H1b: Gamers who experience positive emotions after a stressful match will demonstrate deeper recovery, as indicated by a greater reduction in cardiovascular activation.

A second objective of this study was to determine which physiological indicators most effectively capture the recovery process (Research Question 2). Prior research has predominantly focused on HR (Behnke et al., 2022, 2023), but HR alone does not allow for a clear distinction between sympathetic and parasympathetic activity (Behnke et al., 2022). To address this limitation, the current study incorporated a multi-indicator approach, including (a) PEP - a marker of SNS activity and physiological mobilization; (b) CO - reflecting overall cardiac efficiency and task engagement; and (c) HRV - an index of parasympathetic function and recovery. Together, these measures offer a comprehensive view of autonomic dynamics, capturing both stress mobilization and post-task recovery.

Participants

The study involved CS2 players ($N = 155$), aged between 18 and 36 years ($M = 21.97$, $SD = 2.83$). On average, participants had approximately 15 years of esports experience ($M = 14.94$, $SD = 7.99$) and reported playing CS2 for about 13 hours per week ($M = 12.45$, $SD = 9.46$). According to Steam records, the average total playtime in CS2 was 2,237.29 hours.

In terms of competitive experience 108 participants (69.7%) had never competed in esports tournaments, 41 (26%) had experience in local tournaments, 2 (1.3%) had participated in international tournaments, and 4 (2.6%) had competed in national tournaments. Most participants ($N = 144$; 92.9%) did not earn income from their esports activity, while 11 (7.1%) reported receiving supplementary income through esports involvement.

The highest ranks achieved by players over the previous 12 months were as follows: Global Elite ($N = 22$; 14.2%), Silver Elite ($N = 2$; 1.3%), Distinguished Master Guardian ($N = 14$; 9%), Legendary Eagle ($N = 14$; 9%), Master Guardian I ($N = 19$; 12.3%), Legendary Eagle Master ($N = 14$; 9%), Master Guardian I ($N = 9$; 5.8%), Master Guardian II ($N = 15$; 9.7%), Gold Nova Master ($N = 11$; 7.1%), Silver Elite Master ($N = 1$; 0.6%), Silver I ($N = 3$; 1.9%), Silver II ($N = 3$; 1.9%), Silver III ($N = 1$; 0.6%), Silver IV ($N = 1$; 0.6%), Supreme Master First Class ($N = 11$; 7.1%), Gold Nova I ($N = 4$; 2.6%), Gold Nova II ($N = 4$; 2.6%), Gold Nova III ($N = 5$; 3.2%).

Exclusions

Three participants were excluded from the analysis due to insufficient Polish language proficiency. Although they were able to communicate in everyday situations, it became apparent during the session that they had difficulty reading and fully understanding the study materials and instructions provided in Polish. An additional three participants were excluded from the physiological analysis due to medical factors: diabetes ($N = 2$) and hormonal therapy ($N = 1$). These conditions were disclosed informally during post-session conversations, after

the data collection had taken place. One participant was excluded due to a BMI exceeding 35. Although the participant had initially been approved for the study, it was later determined that the BMI exceeded the eligibility criteria. This oversight was due to researcher error during the initial screening process. In three cases, technical issues resulted in failed ECG and ICG recordings, leading to further exclusion from physiological analyses. Furthermore, data from one participant's recovery phase were lost due to a power outage during the session. As a result, full analyses - including both physiological data and questionnaire responses - were conducted on a final sample of 144 participants.

Ethics

The research was approved by the Ethics Committee of the Faculty of Psychology and Cognitive Science at Adam Mickiewicz University in Poznan (approval no. 01/10/2023).

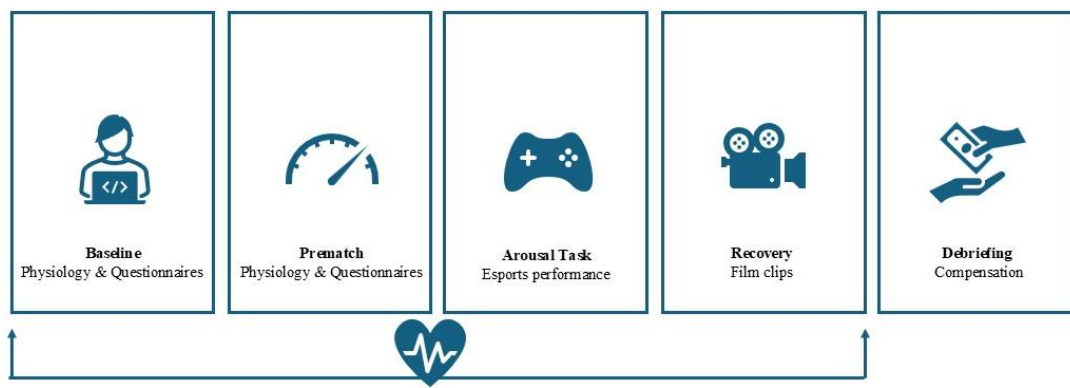
Procedure

Upon arrival at the laboratory, participants received a detailed explanation of the study procedures, and the equipment involved. After providing informed consent, the physiological monitoring setup began. ECG and ICG sensors were applied using pre-gelled AgCl electrodes, with signals recorded using the Vrije Universiteit Ambulatory Monitoring System (VU-AMS, Netherlands). The study followed a structured protocol. Participants completed a 5-minute resting baseline measurement to establish physiological benchmarks. They also completed self-report questionnaires to assess their emotional state and reviewed the initial instructions. Then, participants completed a 2-minute prematch baseline measurement and self-report questionnaires to assess their psychophysiological state immediately before esports performance. After baseline measures, gamers engaged in a single 10-minute match against expert-level bots on the Dust II map in CS2. CS2 was selected due to its demonstrated ability to reliably evoke strong emotional and physiological responses (Behnke et al., 2021, 2024). Following the match, participants watched five 2-minute film clips designed either to elicit

amusement or to maintain a neutral emotional state. They subsequently completed self-report questionnaires to assess their emotional state. After completing the final assessments, participants were debriefed and received a participation voucher. The full procedure lasted approximately 120 minutes (see Figure 1).

Figure 1

Study Procedure



Note. Physiology was continuously recorded throughout the study phases.

Measures

Cardiac Measures

Cardiac data were collected using the VU-AMS, a non-invasive system for monitoring cardiac activity via ECG and ICG. Following psychophysiological guidelines (Sherwood et al., 1990), pre-gelled AgCl electrodes (Kendall Abro, H98SG) were applied using a standard Lead II configuration for ECG and a four-spot array for ICG. Recordings were processed using VU-AMS Data, Analysis & Management Software (VU-DAMS 5.4.24). Key cardiac events (B, C, X, and R points) were manually reviewed and corrected as needed by two independent researchers (the author and SJB - a member of research team). The following

physiological parameters were extracted: HR, PEP, CO, and HRV. HR was measured as beats per minute and IBIs. An increased HR is considered a marker of task engagement and physiological readiness for performance (Behnke et al., 2020; Behnke & Kaczmarek, 2018; Hase et al., 2025; Seery, 2013). IBIs reflect the time interval (in milliseconds) between two successive heartbeats. Shorter IBIs indicate a faster HR, while longer IBIs reflect a slower HR. Greater variability in IBI (i.e., irregular spacing) is typically associated with higher parasympathetic (vagal) tone and better physiological adaptability. PEP was measured as the time in milliseconds from the onset of ventricular depolarization to the opening of the aortic valve. A shorter PEP reflects increased sympathetic activation and it is considered an indicator of task engagement and physiological preparedness for performance (Behnke & Kaczmarek, 2018; Hase et al., 2025; Seery, 2013). CO was measured as the volume of blood pumped by the heart per minute (liters), calculated as SV (the amount of blood ejected per beat) multiplied by HR. Higher CO indicates greater physiological mobilization (Behnke & Kaczmarek, 2018; Hase et al., 2025; Seery, 2013). HRV was reported using RMSSD, which is a time-domain HRV measure that quantifies short-term variations in HR. Higher RMSSD values indicate greater PNS activity and enhanced autonomic flexibility. HRV is widely recognized as a reliable index of parasympathetic activity (Shaffer & Ginsberg, 2017).

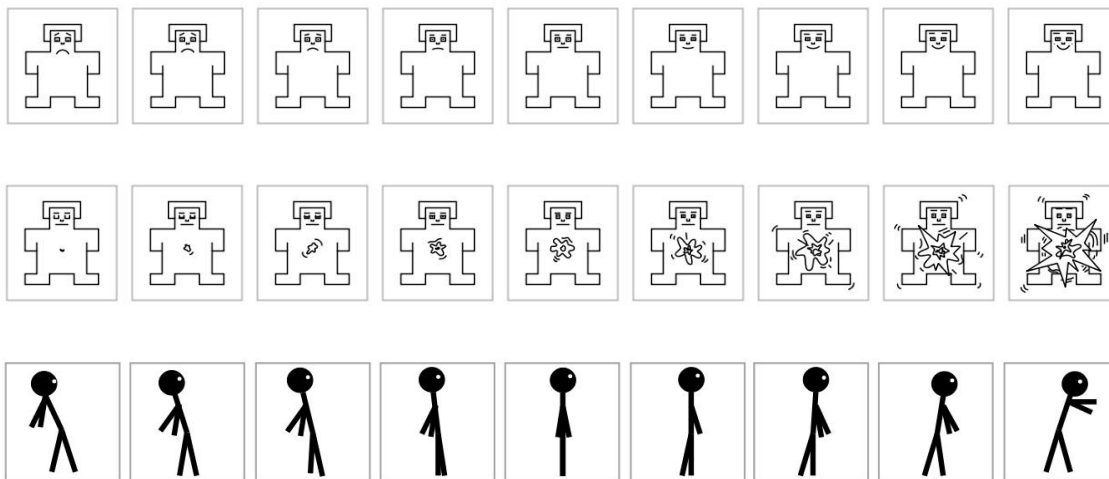
Affective Experience

To assess affective experience, participants rated their emotions and stress at the end of the baseline, prematch, and recovery phases. Participants completed the Differential Emotions Scale (Fredrickson, 2013) to measure discrete emotional responses. Positive affect included amusement, enthusiasm, joy, and pride, while negative affect included anger, fear, overwhelm, and stress. Items were rated on a 7-point scale (1 = *strongly disagree*, 7 = *strongly agree*). The scales demonstrated good internal consistency, with Cronbach's α ranging from .69 to .82. Participants also completed the Self-Assessment Manikin (Bradley &

Lang, 1994; Kaczmarek et al., 2021) to assess dimensional emotional responses: valence, arousal, and motivation, using a 9-point scale (1 = *extremely negative/low arousal/avoidance*; 9 = *extremely positive/high arousal/approach*, see Figure 2).

Figure 2

The Self-Assessment Manikin Scales



Note. The first scale measures valence (from negative to positive), the second measures arousal (from low to high), and the third measures motivation (from backward movement and retreating hands to forward movement and reaching) (Kaczmarek et al., 2021).

Esports Performance

Performance was primarily assessed via the match score, automatically generated by the game system. As a standard procedure, scores were calculated by multiplying points for opponent eliminations by the weapon difficulty level. A higher score reflects better performance. Additional performance metrics included number of eliminations, assists, and deaths.

Problematic Gaming

The Gaming Disorder Test (GDT; Pontes et al., 2021) was used to screen for problematic gaming behaviors during recruitment process. The GDT aligns with the ICD-11 criteria (World Health Organization, 2018) and is a validated psychometric tool (Polish adaptation by Cudo et al. 2022). Participants who responded with a “4” (*Often*) or “5” (*Very Often*) to all items were excluded from the recruitment sample and not invited to participate in the study due to suspected problematic gaming behavior.

Demographic Data

Demographic information was collected via an online form (Microsoft Forms 2024, Microsoft Corporation). Participants reported their level of competition (i.e. recreational, local, national, international), professionalism in esports (i.e. full-time esports job, part-time esports job, or non-income activity), weekly gaming time (in hours), gaming experience, and in-game rank (measured as the highest rank achieved in the past 12 months). Additionally, participants provided their age, BMI, and contact details for scheduling the laboratory session.

Materials

Video Stimuli

Film clips were selected to ensure consistent emotional experience, with the positive videos designed to elicit amusement and the neutral videos designed to maintain an emotionally neutral state. Five 2-minute film clips were selected to elicit positive emotions during the recovery phase. These clips were drawn from validated emotion-eliciting video databases (Gilman et al., 2017; Schaefer et al., 2010) and were chosen for their high amusement value and demonstrated reliability. The selected positive clips included (a) *A Fish Called Wanda* - Archie waits for his girlfriend and unexpectedly ends up naked in front of the homeowners (Schaefer et al., 2010); (b) *When Harry Met Sally* - Sally humorously fakes an

orgasm during a conversation about relationships with Harry at lunch (Schaefer et al., 2010); (c) *The Visitors* - A knight and squire mug someone and wreak havoc on a car (Schaefer et al., 2010), (d) *Benny and Joon* - Benny entertains with food-puppets, playfully interacting with people in a diner (Schaefer et al., 2010), and (e) *The Office* - Dwight's fire drill triggers chaotic reactions in the office (Gilman et al., 2017).

Additional five 2-minute clips were selected to elicit a neutral emotional state. These clips were also validated for emotional neutrality (Jenkins & Andrewes, 2012; Kosakowski, 2021; Schaefer et al., 2010) and included (a) *Blue* - Scenes of a man clearing his desk drawers and a woman walking down an alley and briefly greeting another person (two clips; Schaefer et al., 2010); (b) *The Lover* - Scenes of a woman walking down the street, driving, observing a large ship in port, or a waiter cleaning tables (Schaefer et al., 2010); (c) *Twin Peaks* - A man quietly sweeping the floor of an empty club (Kosakowski, 2021), and (d) *Lost in Translation* - Scenes of a woman sitting on a bed, looking out a window over the city, or a man getting up and taking an elevator (Jenkins & Andrewes, 2012).

Data Analysis Strategy

This section outlines the analytical approach used to examine the study data. It begins with procedures for identifying and handling outliers to ensure data quality, followed by manipulation checks assessing participant engagement, physiological responses, emotional states, and the effectiveness of the experimental manipulation. Then, the main hypotheses are tested, followed by a multiverse analysis to evaluate the robustness of findings.

Outlier Treatment

Outliers were identified and removed using the Median Absolute Deviation (MAD) method with a cut-off score of 3, following recommendations by Leys et al. (2013, 2019). Although an additional analysis that included all data points revealed no statistically significant differences in the main outcomes, the presence of extreme values noticeably

distorted the means and standard deviations of key physiological variables. This skewness compromised the interpretability and reliability of certain analyses. Therefore, for greater methodological rigor and more accurate estimation of central tendencies, all analyses were conducted on data with outliers excluded.

Manipulation Checks

Did the Gamers Engage in the Study? To assess whether gamers were physiologically engaged in the study, a repeated-measures ANOVA was conducted to examine changes in physiological responses across four phases: baseline, prematch, match, and recovery. Increased HR and shortened PEP from baseline to match were used as indicators of physiological engagement. Mauchly's test of sphericity was applied and the Greenhouse-Geisser correction was used when necessary. To assess the effect size, generalized eta squared (η^2_G) was used.

Did the Gamers in the Experimental and Control Groups Differ in the Intensity of Emotions They Experienced? To assess whether gamers in both groups faced the match in a similar emotional state, a series of t-tests were conducted to compare emotions during baseline and prematch phases between the experimental and control groups. Levene's test was used to verify the assumption of homogeneity of variance.

Did the Gamers in the Experimental and Control Groups Differ in Their Physiological Responses From Baseline to the Match? To assess whether gamers in both groups faced the match in a similar physiological state, a repeated-measures ANOVA was conducted to compare physiological responses across the baseline, prematch, and match phases between experimental and control groups. To assess the effect size, generalized eta squared (η^2_G) was used.

Did the Gamers in the Experimental Group Feel More Positive Emotions Than Gamers in the Control Group After Watching the Film Clips? To assess the effectiveness of the positive emotions elicitation, t-tests were conducted to compare positive emotions ratings during the recovery phase between the experimental and control groups. Levene's test was used to assess the assumption of homogeneity of variance. Additionally, within the experimental group, a repeated-measures ANOVA was conducted to determine whether gamers reported feeling more amusement than any other positive emotion. To assess the effect size, generalized eta squared (η^2_G) was used.

Hypotheses Testing

Did Positive Emotions Optimize Recovery After Esports Performance? ECG and ICG differ in temporal resolution, which influences their respective analytical approaches. ECG allows for more precise, beat-by-beat analyses with a resolution measured in seconds, whereas ICG data are typically averaged over 1-minute bins, offering a coarser resolution measured in minutes (Sherwood et al., 1990). To test the undoing hypothesis - whether positive emotions optimize cardiovascular recovery from esports-related arousal in terms of speed (i.e., gamers recovered faster) - analysis was conducted using ECG-derived IBIs. A moving average was applied, using the current heartbeat and the five subsequent beats, to estimate the precise duration of IBI recovery. A participant was considered to have returned to baseline once this moving average fell within the predefined baseline range and remained there for at least five consecutive beats (Fredrickson & Levenson, 1998). Two recovery operationalizations were used: time-to-IBI-baseline-level and time-to-IBI-threshold (defined as the baseline mean IBI minus one standard deviation, as in Fredrickson & Levenson, 1998). This approach enabled a continuous measure of recovery time, offering greater temporal precision than the minute-based analysis.

Multiverse Analysis

Did the Results Remain Consistent Across Different Recovery

Operationalizations and Analytical Strategies? Psychological research often involves numerous analytical decisions (e.g., exclusion criteria, data transformations, statistical model selection) that can influence results (Steege et al., 2016). Similarly, researchers may choose from various ways to operationalize psychological constructs (e.g., differing scales or definitions), further contributing to variability in findings. The multiverse approach systematically evaluates the robustness of results by analyzing all reasonable variations in data processing and operationalization choices, rather than relying on a single, potentially arbitrary decision (Steege et al., 2016). This strategy enhances transparency and reduces the risk of selective reporting by demonstrating how different analytical paths influence conclusions. By revealing whether a result remains consistent across analytical choices or is contingent on specific decisions, multiverse analysis strengthens the credibility of psychological research and addresses concerns related to replicability and questionable research practices (Steege et al., 2016). Thus, the analyses were re-run using other justified approaches and possible operationalizations of recovery. Physiological recovery was defined in two ways (a) the time in minutes it took for gamers to return to their baseline physiological state following the match; and (b) the difference in physiological values between the last minute of the match and various recovery intervals (the first minute, two minutes, and ten minutes).

Time-to-Baseline. To address potential skewness in the time-to-IBI-baseline and time-to-IBI-threshold variables, a natural-log transformation, $\log_e(x + 1)$, was applied. Analyses were then re-run using the log-transformed data. Additionally, to test the undoing effect - whether positive emotions optimize cardiovascular recovery from esports-related arousal in terms of speed (i.e., gamers recovered faster) - and to account for the differing temporal

resolution of ECG and ICG data, a minute-based analysis was used. This analysis identified how many participants returned to baseline during each of the ten minutes of the recovery phase for each physiological measure: HR, PEP, CO, and HRV.

Recovery Intervals. To test the undoing effect - whether positive emotions optimize cardiovascular recovery from esports-related arousal in terms of depth (i.e., gamers displayed greater reduction in cardiovascular activation) - *t*-tests were conducted to compare HR, PEP, CO, and HRV between the experimental and control groups. Recovery was operationalized as the difference between physiological values during the last minute of the match and the first minute of the recovery. Levene's test was used to assess the assumption of homogeneity of variance. Additionally, to control for physiological activation at the end of the match, ANCOVAs were conducted with physiological values during the last minute of the match as covariates. Recovery was also examined across two extended intervals: (a) the average of the first two minutes, and (b) the average of the full ten-minute recovery phase. For both intervals, differences between match and recovery values were calculated.

Non-parametric Testing. To address potential deviations from normality in the data, parametric analyses were used as the primary inferential approach, with non-parametric tests included as part of a multiverse analysis. Parametric tests are considered robust to violations of normality and other assumptions (Norman, 2010). They also preserve the full informational value of interval-scale data and offer greater statistical power compared to non-parametric alternatives, which rely on data ranking. Simulation studies have shown that non-parametric methods can lead to a significant loss of power, failing to detect true effects (Vickers, 2005; Tsagris et al., 2020). Consistent with current best practices, outliers were identified and handled using the MAD method, sample sizes were transparently reported, and key assumptions such as homogeneity of variance were tested (Lakens, 2013). Non-parametric

tests were incorporated into the multiverse analysis to provide a more comprehensive and robust analytical framework (Steege et al., 2016).

Chapter 7. Results

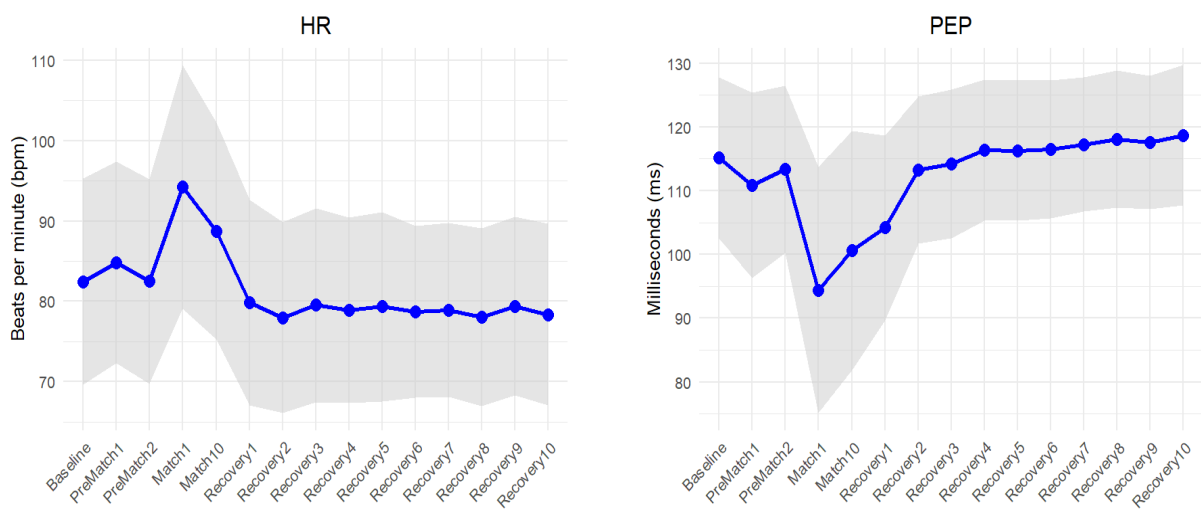
Manipulation Checks

Did the Gamers Engage Physiologically in the Study?

HR. A repeated-measures ANOVA with Greenhouse-Geisser correction revealed that gamers were engaged in the study; their HR changed from baseline, through match to recovery, $F(3.78; 525.42) = 132.66; p < .001; \eta^2_G = 0.13$, indicating a large effect size (see Figure 3 and Table 2).

Figure 3

Gamers' Physiological Engagement During Study Phases



Note. Baseline, PreMatch, Match, and Recovery refer to the study phases. The accompanying numbers indicate the minute within each phase (e.g., PreMatch1 refers to the first minute of the prematch phase).

Table 2*Descriptive Statistics for HR and PEP During Study Phases*

Study Phase	HR	PEP
	<i>M(SD)</i>	<i>M(SD)</i>
Baseline	82.47 (12.81)	115.12 (12.62)
PreMatch1	84.84 (12.50)	110.80 (14.54)
PreMatch2	82.50 (12.72)	113.38 (13.13)
Match1	94.22 (15.14)	94.40 (19.30)
Match10	88.75 (13.45)	100.62 (18.79)
Recovery1	79.48 (13.00)	103.33 (14.32)

Note. Baseline, PreMatch, Match, and Recovery refer to the study phases. The accompanying numbers indicate the minute within each phase (e.g., PreMatch1 refers to the first minute of the prematch phase, while Match10 refers to the tenth and final minute of the match).

Then, a series of t-tests showed the following:

- No difference between the last minute of the baseline and the last minute of the prematch, $t = -0.60$; $p = 1.00$; Cohen's $d = -0.05$ [-0.22; 0.11], indicating a negligible effect size; gamers exhibited similar HR patterns during the baseline and prematch phases.
- A difference between the last minute of the prematch and the first minute of the match, $t = -11.60$; $p < .001$; Cohen's $d = -0.98$ [-1.20; -0.82], indicating a large effect size; gamers had lower HR during the last minute of the prematch compared to the first minute of the match.
- A difference between the last minute of the prematch and the last minute of the match, $t = -8.56$; $p < .001$; Cohen's $d = -0.72$ [-0.89; -0.58], indicating a medium to large effect size; gamers had lower HR during the last minute of the prematch compared to the last minute of the match.

- A difference between the last minute of the match and the first minute of the recovery, $t = 14.20$; $p < .001$; Cohen's $d = 1.20$ [1.02; 1.41], indicating a large effect size; gamers had higher HR during the last minute of the match compared to the first minute of the recovery.

PEP. A repeated-measures ANOVA with Greenhouse-Geisser correction revealed that gamers were engaged in the study; their PEP changed from baseline, through match to recovery, $F(4.06; 483.14) = 100.56$; $p < .001$; $\eta^2_G = 0.22$, indicating a large effect size (see Figure 3 and Table 2). Then, the series of t-tests showed the following:

- No difference between the last minute of the baseline and the last minute of the prematch, $t = 2.31$; $p = 1.00$; Cohen's $d = 0.21$ [0.01; 0.40], indicating a small effect size; gamers exhibited similar PEP patterns during the baseline and prematch phases.
- A difference between the last minute of the prematch and the first minute of the match, $t = 12.90$; $p < .001$; Cohen's $d = 1.18$ [1.02; 1.38], indicating a large effect size; gamers had higher PEP during the last minute of the prematch compared to the first minute of the match.
- A difference between the last minute of the prematch and the last minute of the match, $t = 8.19$; $p < .001$; Cohen's $d = 0.75$ [0.58; 0.92], indicating a medium to large effect size; gamers had higher PEP during the last minute of the prematch compared to the last minute of the match.
- No difference between the last minute of the match and the first minute of the recovery, $t = -2.82$; $p = .60$; Cohen's $d = -0.26$ [-0.41; -0.09], indicating a small effect size; gamers had lower PEP during the last minute of the match compared to the first minute of the recovery, but the difference was not statistically significant.

Together, these results indicate that gamers demonstrated physiological engagement during the match, as evidenced by increased HR and shortened PEP - markers of physiological mobilization in response to esports performance demands.

Did the Gamers in the Experimental and Control Groups Differ in the Intensity of Emotions They Experienced?

Baseline. There were no significant differences in baseline discrete emotions between the groups, except for excitement, which was lower in the experimental group with small to medium effect size. Additionally, no significant differences were found in baseline valence, arousal, or motivation between the experimental and control groups (see Table 3).

Visualizations of emotional changes across study phases are presented in Figure 4 (discrete emotions) and Figure 5 (dimensional emotions).

Figure 4

Emotions During the Study - Discrete Approach

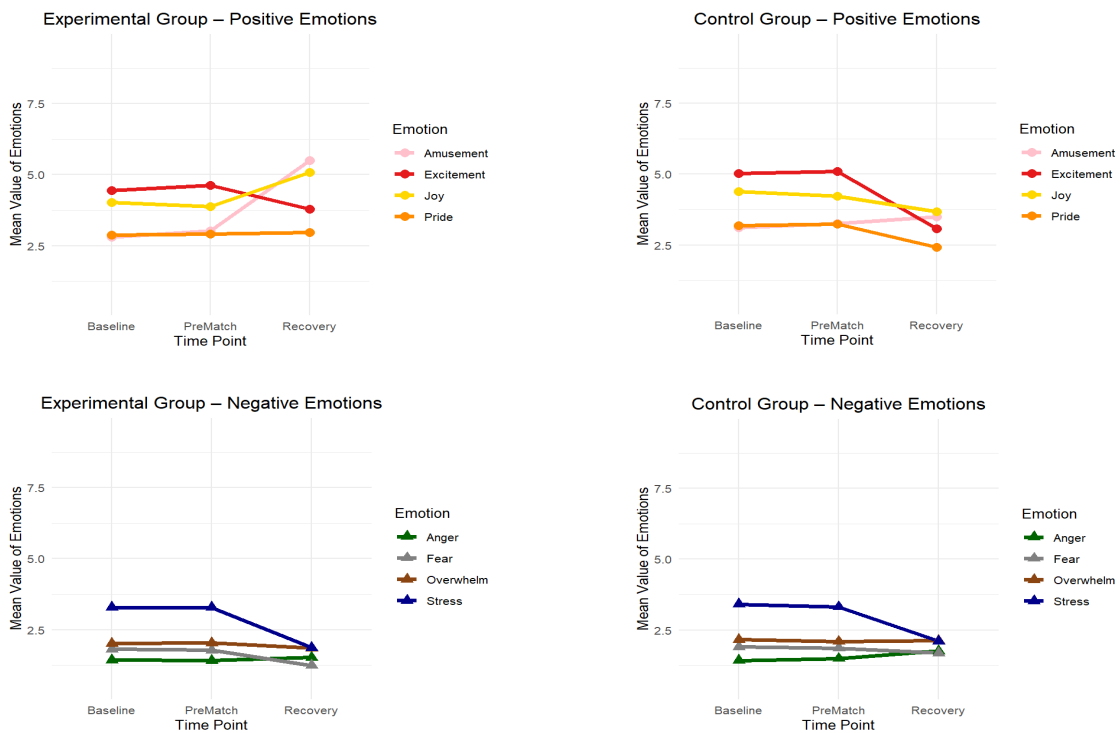
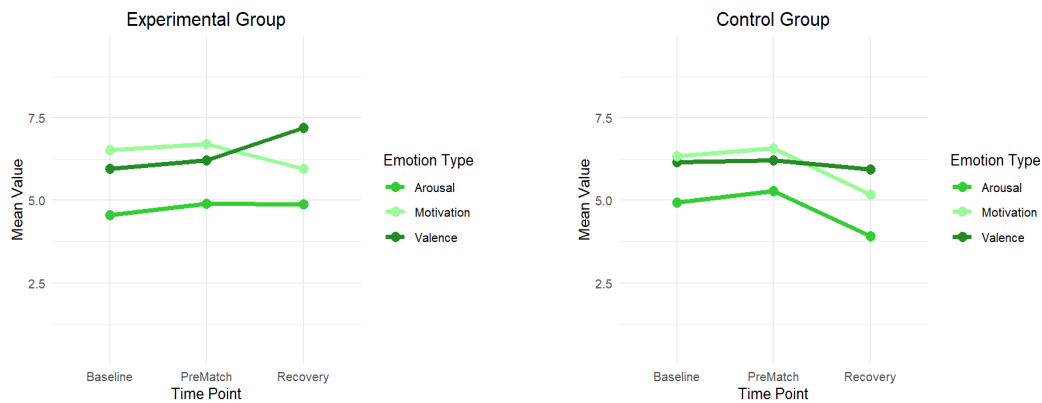


Figure 5*Emotions During the Study - Dimensional Approach***Table 3***Baseline Affect: Descriptive Statistics and Group Comparisons*

Affect	Experimental Group	Control Group	<i>t</i>	<i>df</i>	Cohen's <i>d</i> [95%CI]
	<i>M</i> (<i>SD</i>)	<i>M</i> (<i>SD</i>)			
Discrete					
Amusement	2.81 (1.46)	3.11 (1.56)	-1.23	149	-0.20 [-0.52; 0.12]
Excitement	4.45 (1.51)	5.03 (1.03)	-2.77**	136.37	-0.44 [-0.77; -0.12]
Joy	4.03 (1.58)	4.38 (1.32)	-1.51	149	-0.25 [-0.57; 0.08]
Pride	2.87 (1.64)	3.19 (1.40)	-1.29	149	-0.21 [-0.53; 0.11]
Anger	1.44 (0.99)	1.42 (0.88)	0.07	149	0.01 [-0.31; 0.33]
Fear	1.82 (1.08)	1.90 (1.25)	-0.44	149	-0.07 [-0.39; 0.25]
Overwhelm	2.01 (1.50)	2.16 (1.40)	-0.64	149	-0.10 [-0.43; 0.22]
Stress	3.28 (1.43)	3.41 (1.53)	-0.54	149	-0.09 [-0.41; 0.23]
Dimensional					
Valence	5.95 (1.20)	6.15 (1.28)	-1.00	149	-0.16 [-0.49; 0.16]
Arousal	4.55 (1.45)	4.93 (1.58)	-1.56	148	-0.25 [-0.58; 0.07]
Motivation	6.53 (1.78)	6.34 (1.66)	0.65	149	0.11 [-0.22; 0.43]

Note. Hedges' *g* was used as an effect size for excitement due to violated homogeneity.

***p* < .01.

Prematch. Similarly, there were no significant differences in prematch discrete emotions between the groups, except for excitement, which was lower in the experimental group with small effect size. Additionally, no significant differences were found in prematch valence, arousal, or motivation between the experimental and control groups (see Table 4, Figure 4 & 5).

Table 4

Prematch Affect: Descriptive Statistics and Group Comparisons

Affect	Experimental group	Control Group	<i>t</i>	<i>df</i>	Cohen's <i>d</i> [95%CI]
	<i>M</i> (<i>SD</i>)	<i>M</i> (<i>SD</i>)			
Discrete					
Amusement	3.03 (1.48)	3.26 (1.50)	-0.97	149	-0.16 [-0.48; 0.16]
Excitement	4.62 (1.49)	5.10 (1.18)	-2.21*	145.18	-0.35 [-0.68; -0.03]
Joy	3.87 (1.73)	4.22 (1.38)	-1.36	148	-0.22 [-0.55; 0.10]
Pride	2.91 (1.69)	3.25 (1.55)	-1.27	149	-0.21 [-0.53; 0.12]
Anger	1.41 (0.87)	1.50 (0.93)	-0.56	149	-0.09 [-0.41; 0.23]
Fear	1.78 (1.06)	1.86 (1.33)	-0.41	149	-0.07 [-0.39; 0.25]
Overwhelm	2.04 (1.39)	2.10 (1.37)	-0.26	149	-0.04 [-0.36; 0.28]
Stress	3.28 (1.47)	3.32 (1.67)	-0.13	149	-0.02 [-0.34; 0.30]
Dimensional					
Valence	6.21 (1.11)	6.21 (1.19)	-0.00	149	-0.00 [-0.32; 0.32]
Arousal	4.90 (1.57)	5.29 (1.68)	-1.48	149	-0.24 [-0.56; 0.08]
Motivation	6.69 (1.78)	6.58 (1.57)	0.43	149	0.07 [-0.25; 0.39]

Note. Hedges' *g* was used as an effect size for excitement due to violated homogeneity.

**p* < .05.

Did the Gamers in the Experimental and Control Groups Differ in Their Physiological Responses from Baseline to the Match?

Four repeated-measures ANOVAs were conducted to examine differences between the experimental and control groups in HR, PEP, CO, and HRV. No significant differences were found between the groups for:

- HR, $F(1, 140) = 1.81; p = .18; \eta^2_G = 0.01;$
- PEP, $F(1, 129) = 0.01; p = .91; \eta^2_G = 0.00;$
- CO, $F(1, 130) = 1.10; p = .30; \eta^2_G = 0.01;$
- HRV, $F(1, 125) = 0.56; p = .45; \eta^2_G = 0.00.$

Effect sizes were negligible. Thus, gamers in the experimental and control groups did not differ in their physiological responses from baseline to the match (see Table 5).

Additionally, no significant interaction effects were observed between study condition (experimental vs. control group) and study phase for:

- HR, $F(2.08; 291.20) = 0.39; p = .82; \eta^2_G = 0.00;$
- PEP, $F(2.08, 268.32) = 0.19; p = .94; \eta^2_G = 0.00;$
- CO, $F(2.20, 286) = 0.52; p = .72; \eta^2_G = 0.00;$
- HRV, $F(2.64, 330) = 0.74; p = .56; \eta^2_G = 0.00.$

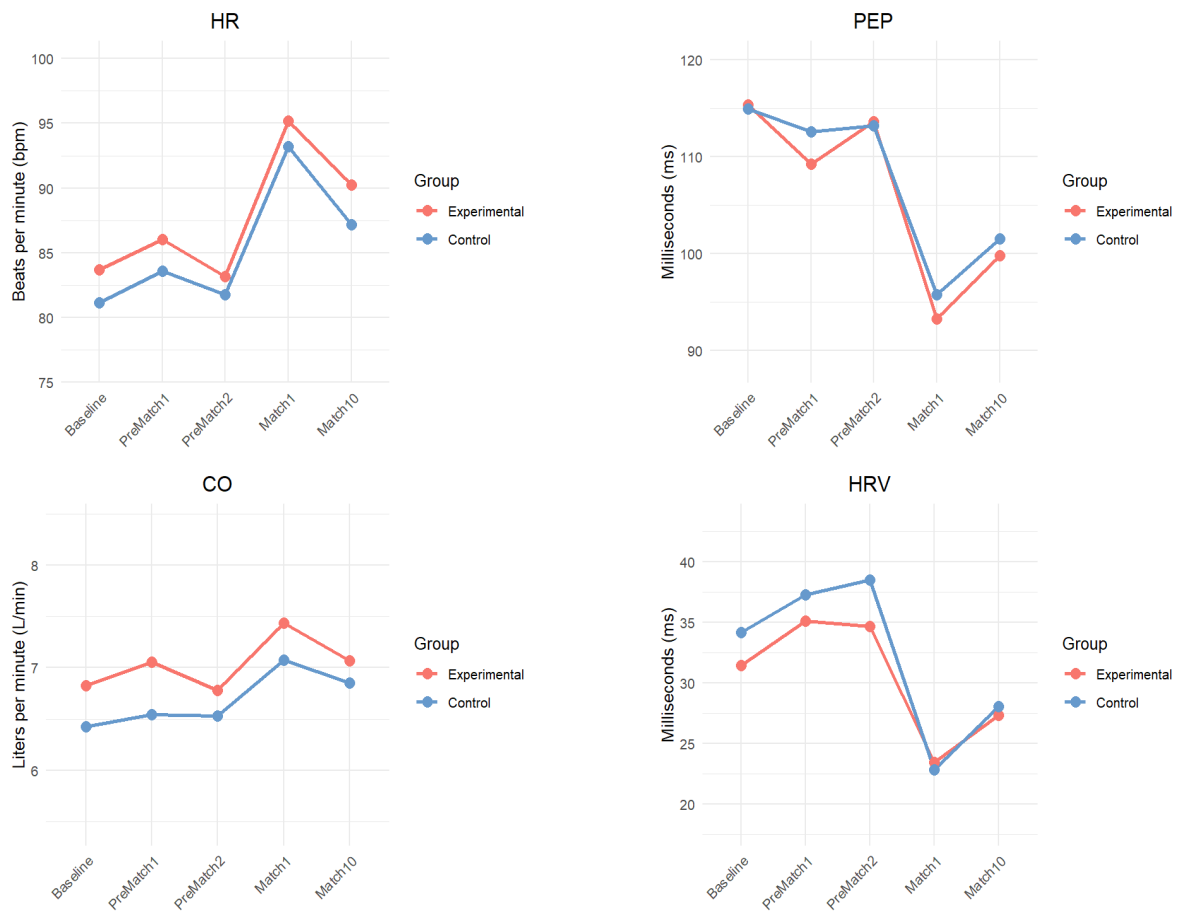
However, a significant main effect of study phase was found for:

- HR, $F(2.08; 291.20) = 93.97; p < .001; \eta^2_G = 0.10,$ indicating medium effect size;
- PEP, $F(2.08, 268.32) = 109.94; p < .001; \eta^2_G = 0.20,$ indicating large effect size;
- CO, $F(2.20, 286) = 38.55; p < .001; \eta^2_G = 0.03,$ indicating small effect size;
- HRV, $F(2.64, 330) = 46.40; p < .001; \eta^2_G = 0.11,$ indicating medium effect size.

Thus, gamers exhibited resting physiological patterns during the baseline and heightened physiological mobilization during the match (see Figure 6).

Figure 6

Physiological Patterns for Experimental and Control Groups From Baseline to Match



Note. Baseline, PreMatch, and Match refer to the study phases. The accompanying numbers indicate the minute within each phase (e.g., PreMatch1 refers to the first minute of the prematch phase, while Match10 refers to the tenth and final minute of the match).

Table 5*Descriptive Statistics and Group Differences in Physiology From Baseline to Match*

Study phase	Experimental group	Control group	<i>t</i>	<i>df</i>	Cohen's <i>d</i> [95%CI]
	<i>M(SD)</i>	<i>M(SD)</i>			
HR					
Baseline	83.70 (13.19)	81.15 (12.35)	1.36	140	0.23 [-0.08; 0.59]
Prematch1	86.03 (12.26)	83.59 (12.72)	1.49	140	0.25 [-0.10; 0.61]
Prematch2	83.18 (12.81)	81.78 (12.68)	1.09	140	0.18 [-0.14; 0.52]
Match1	95.18 (15.51)	93.20 (14.77)	0.75	140	0.13 [-0.23; 0.44]
Match10	90.23 (13.91)	87.16 (12.84)	1.54	140	0.26 [-0.06; 0.61]
PEP					
Baseline	115.35 (12.96)	114.89 (12.36)	0.24	129	0.04 [-0.30; 0.39]
Prematch1	109.19 (15.78)	112.56 (12.95)	-0.58	129	-0.10 [-0.45; 0.27]
Prematch2	113.59 (13.07)	113.15 (13.29)	0.10	129	0.02 [-0.32; 0.37]
Match1	93.23 (19.88)	95.73 (18.68)	-0.12	129	-0.02 [-0.36; 0.29]
Match10	99.80 (19.63)	101.52 (17.92)	-0.11	129	-0.02 [-0.37; 0.34]
CO					
Baseline	6.83 (1.34)	6.42 (1.40)	1.16	130	0.20 [-0.11; 0.55]
Prematch1	7.05 (1.40)	6.54 (1.43)	1.45	130	0.25 [-0.08; 0.58]
Prematch2	6.78 (1.19)	6.53 (1.43)	0.88	130	0.15 [-0.17; 0.48]
Match1	7.44 (1.62)	7.07 (1.56)	0.73	130	0.13 [-0.22; 0.47]
Match10	7.07 (1.31)	6.85 (1.52)	0.81	130	0.14 [-0.19; 0.49]
HRV					
Baseline	31.46 (16.98)	34.15 (16.01)	-0.83	125	-0.15 [-0.51; 0.20]
Prematch1	35.09 (16.27)	37.27 (15.51)	-0.58	125	-0.10 [-0.44; 0.26]
Prematch2	34.65 (17.79)	38.50 (17.61)	-1.15	125	-0.20 [-0.55; 0.15]
Match1	23.45 (12.88)	22.80 (11.70)	0.22	125	0.04 [-0.29; 0.40]
Match10	27.33 (15.12)	28.03 (14.02)	-0.54	125	-0.10 [-0.45; 0.28]

Note. Baseline, PreMatch, and Match refer to the study phases. The accompanying numbers indicate the minute within each phase (e.g., Match1 refers to the first minute of the match).

Did the Gamers in the Experimental Group Feel More Positive Emotions Than Gamers in the Control Group After Watching Film Clips?

Gamers in the experimental group reported experiencing more positive emotions after watching film clips than those in the control group, with large effect sizes for amusement, joy, and overall valence, a medium effect for excitement, and a small effect for pride (see Table 6).

Table 6

Descriptive Statistics and Group Differences in Positive Emotions After Watching Film Clips

Emotion	Experimental Group	Control Group	<i>t</i>	<i>df</i>	Cohen's <i>d</i> [95% CI]
	<i>M</i> (<i>SD</i>)	<i>M</i> (<i>SD</i>)			
Amusement	5.51 (1.37)	3.49 (1.73)	7.91***	136.83	1.29 [0.94; 1.64]
Excitement	3.79 (1.57)	3.07 (1.62)	2.80**	149	0.46 [0.13; 0.78]
Joy	5.08 (1.36)	3.67 (1.52)	6.02***	150	0.98 [0.64; 1.32]
Pride	2.97 (1.67)	2.42 (1.60)	2.07*	150	0.34 [0.01; 0.66]
Valence	7.19 (1.22)	5.95 (1.27)	6.17***	150	1.00 [0.66; 1.34]

Note. For amusement effect size Hedges' *g* was used due to violated homogeneity of variance
p* < .05. *p* < .01. ****p* < .001.

Furthermore, within the experimental group, gamers reported feeling more amusement than any other positive emotion, $F(2.31, 178.22) = 96.91$; $p < .001$; $\eta^2_G = 0.31$ with large effect size (see Table 7).

Table 7*Positive Emotions Among Gamers in Experimental Group After Watching Film Clips*

Amusement	<i>t</i> (77)	Cohen's <i>d</i> [95% CI]
Excitement	10.93 ^{***}	1.15 [0.88; 1.42]
Joy	3.66 ^{***}	0.29 [0.13; 0.45]
Pride	12.43 ^{***}	1.63 [1.24; 2.03]

^{***}*p* < .001.

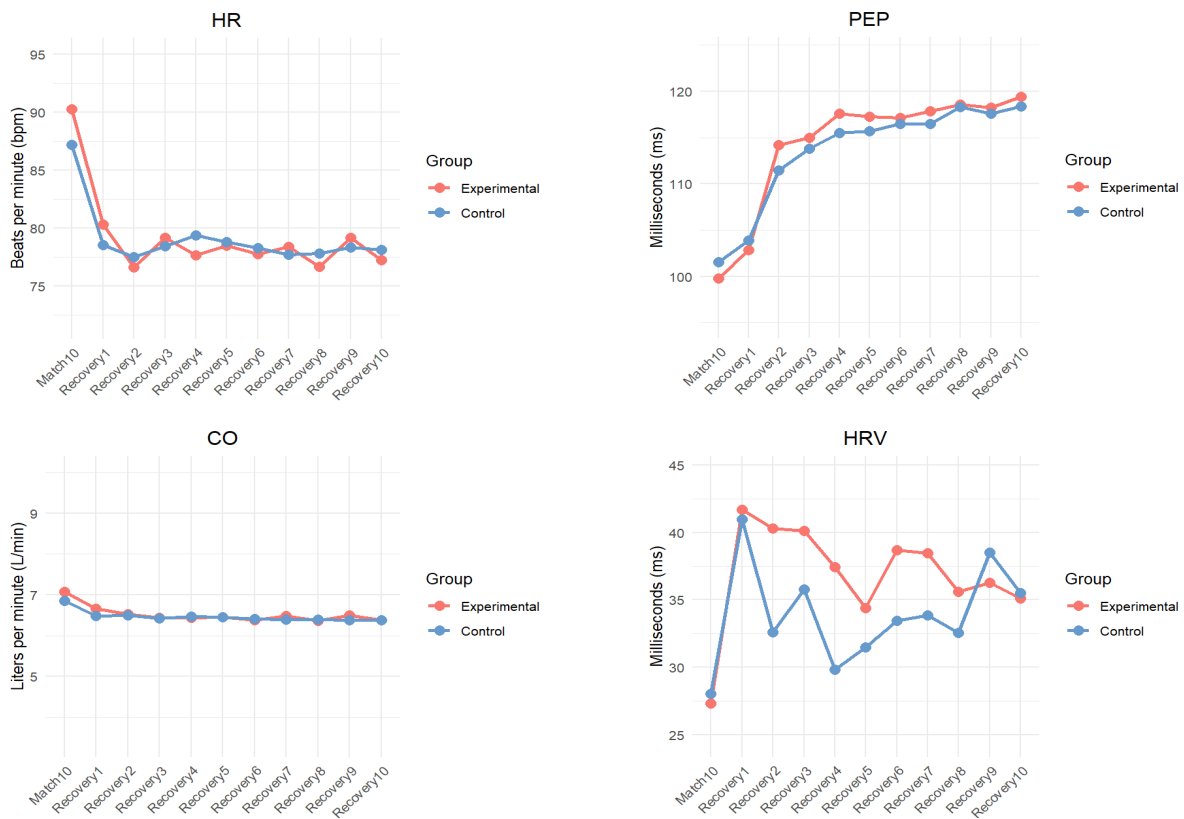
Hypotheses Testing

Did Positive Emotions Optimize Recovery After Esports Performance?

Following the arousing esports tournament, gamers in both groups exhibited clear recovery patterns: HR and CO decreased, while PEP and HRV increased. Figure 7 and Table 8 illustrate the dynamic of the recovery phase for gamers in the experimental and control groups.

Figure 7

Physiological Patterns for Recovery



Note. The plots display the raw values of physiological measures during the match and recovery. Match and Recovery refer to the study phases. The accompanying numbers indicate the minute within each phase (e.g., Recovery1 refers to the first minute of the recovery phase).

Table 8*Descriptive Statistics for HR, PEP, CO, and HRV During Recovery*

Study Phase	Experimental Group	Control Group
	<i>M(SD)</i>	<i>M(SD)</i>
HR		
Match10	90.23 (13.91)	87.16 (12.84)
Recovery1	80.33 (14.05)	78.56 (11.84)
Recovery10	77.22 (11.66)	78.12 (10.70)
PEP		
Match10	99.80 (19.63)	101.52 (17.92)
Recovery1	102.86 (14.90)	103.90 (13.72)
Recovery10	119.40 (10.90)	118.33 (9.90)
CO		
Match10	7.07 (1.31)	6.85 (1.52)
Recovery1	6.66 (1.36)	6.48 (1.52)
Recovery10	6.38 (1.11)	6.38 (1.45)
HRV		
Match10	27.33 (15.12)	28.03 (14.02)
Recovery1	41.68 (18.19)	41.00 (16.04)
Recovery10	35.12(14.25)	35.49 (16.98)

Note. Match and Recovery refer to the study phases. The accompanying numbers indicate the minute within each phase (e.g., Recovery1 refers to the first minute of the recovery phase).

Match10 values are included again to facilitate comparisons.

A moving average analysis of IBIs was used to determine the time required for gamers to return to and remain within baseline levels for five consecutive beats. Two approaches were applied: time-to-IBI-baseline-level and time-to-IBI-threshold (defined as the baseline mean IBI minus one standard deviation, as in Fredrickson & Levenson, 1998). For both approaches, no significant differences were found between the experimental and control groups with small

effect sizes; gamers in both conditions required a similar amount of time to return to baseline and threshold levels. This approach demonstrated that gamers exhibited a rapid physiological recovery following esports performance arousal (see Table 9).

Table 9

Descriptive Statistics and Group Differences in Recovery Time Based on IBIs

	Experimental Group	Control Group	<i>t</i>	<i>df</i>	Cohen's <i>d</i> [95%CI]
	<i>M(SD)</i>	<i>M(SD)</i>			
Time-to-baseline	12.88 (11.45)	14.82 (15.83)	-0.84	125.22	-0.14 [-0.44; 0.19]
Time-to-threshold	3.92 (4.99)	6.18 (10.31)	-1.66	98.50	-0.28 [-0.54; 0.04]

Note. Time-to-baseline and Time-to-threshold are reported in a time required for participants to return to and remain within IBI-baseline and IBI-threshold levels for five consecutive beats.

Multiverse Analysis

Did the Results Remain Consistent Across Different Recovery Operationalizations and Analytical Strategies?

The multiverse analysis examined how different operationalizations of recovery and analytical approaches might influence the results (Steege et al., 2016). First, time-to-baseline analyses were re-run with adjustments for data skewness. Second, a minute-based descriptive analysis was conducted to determine how many gamers returned to baseline during each of the ten minutes of the recovery phase. Third, recovery was also operationalized as the difference in physiological values between the last minute of the match and several recovery intervals (i.e., the first minute, the first two minutes, and the full ten-minute recovery phase). To account for individual differences in physiological activation at the end of the match, ANCOVAs were conducted using physiological values during the last minute of the match as

covariates. The multiverse approach allows researchers to assess the robustness of findings by exploring how different analytical decisions and variable definitions influence the results. This strategy promotes transparency, reduces the risk of selective reporting, and strengthens the overall credibility of psychological research (Steege et al., 2016).

Time-to-Baseline. To account for the positive skewness observed in the time-to-baseline (skewness = 1.58) and time-to-threshold (skewness = 3.52) variables, a $\log_e(x + 1)$ transformation was applied. Analyses were then re-run using the log-transformed data. No significant differences were found between the experimental and control groups with negligible effect sizes. Gamers in both conditions required a similar amount of time to return to baseline levels, $t(133.90) = 0.22$; $p = .83$; Cohen's $d = 0.04$ [-0.32; 0.37], and threshold levels, $t(133.80) = -0.68$; $p = .50$; Cohen's $d = -0.11$ [-0.44; 0.18].

Moreover, a minute-based descriptive analysis was conducted to examine how many gamers returned to baseline during each of the ten minutes of the recovery phase. This overview of recovery patterns revealed that most gamers returned to their baseline levels within the first two minutes of recovery (see Figure 8 and Table 10). However, this descriptive approach also revealed a key limitation: in the context of esports performance, minute-based intervals may not offer optimal temporal resolution for analyzing physiological changes, because some participants had already returned to baseline before the formal recovery phase began.

For HR, 7 gamers (4.86%) never returned to baseline, while 32 (22.22%) had already returned before the recovery phase began. In the experimental group, 2 gamers (2.70%) did not return to baseline, and 18 (24.32%) returned before the recovery phase. In the control group, 5 gamers (7.14%) did not return, and 14 (20.00%) returned prior to recovery.

For PEP, 19 gamers (13.48%) never returned to baseline, and 24 (17.02%) had already returned before the recovery phase began. In the experimental group, 9 gamers (12.16%) did

not return to baseline, and 9 (12.16%) returned before the recovery phase. In the control group, 10 gamers (14.93%) did not return, and 15 (22.39%) returned prior to recovery.

For CO, 11 gamers (7.97%) never returned to baseline, and 36 (26.09%) had already returned before the recovery phase began. In the experimental group, 4 gamers (5.56%) did not return to baseline, and 19 (26.39%) returned before the recovery phase. In the control group, 7 gamers (10.61%) did not return, and 17 (25.76%) returned prior to recovery.

For HRV, 9 gamers (6.25%) never returned to baseline, and 56 (38.89%) had already returned before the recovery phase began. In the experimental group, 2 gamers (2.70%) did not return to baseline, and 34 (45.95%) returned before the recovery phase. In the control group, 7 gamers (10.00%) did not return, and 22 (31.43%) returned prior to recovery. These participants were excluded from the minute-based analyses (i.e., recovery interval analyses, where recovery was defined as the difference between physiological values recorded during the last minute of the match and those recorded during the first, first two, and full ten minutes of the recovery phase).

Figure 8

Number and Percentage of Gamers Returning to Baseline Within Each Minute of the 10-Minute Recovery Phase

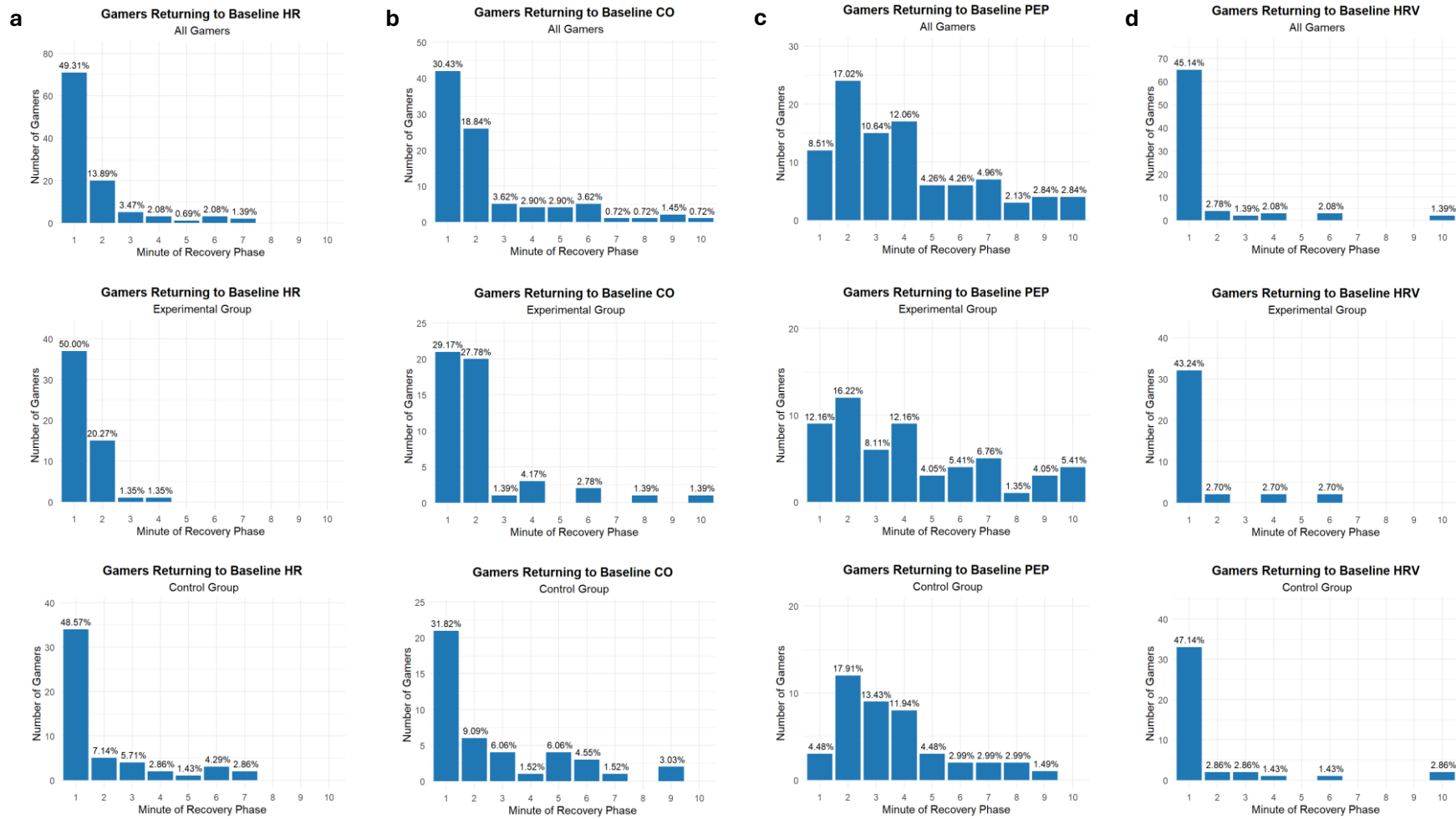


Table 10

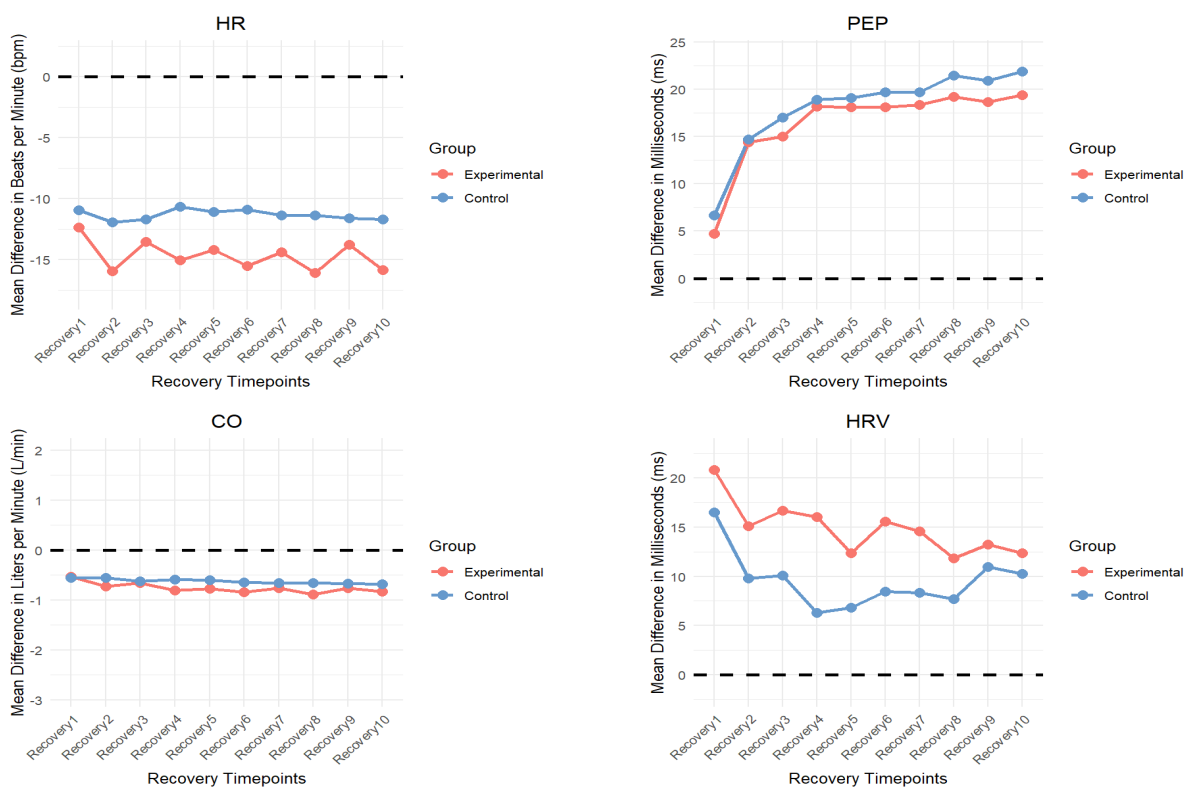
Number and Percentage of Gamers Returning to Baseline Within Each Minute of the 10-Minute Recovery Phase

Recovery Minutes	Total		Experimental Group		Control Group		Recovery Minutes	Total		Experimental Group		Control Group	
	N	%	N	%	N	%		N	%	N	%	N	%
HR							CO						
1	71	49.31	37	50.00	34	48.57	1	42	30.43	21	29.17	21	31.82
2	20	13.89	15	20.27	5	7.14	2	26	18.84	20	27.78	6	9.09
3	5	3.47	1	1.35	4	5.71	3	5	3.62	1	1.39	4	6.06
4	3	2.08	1	1.35	2	2.86	4	4	2.90	3	4.17	1	1.52
5	1	0.69	0	0.00	1	1.43	5	4	2.90	0	0.00	4	6.06
6	3	2.08	0	0.00	3	4.29	6	5	3.62	2	2.78	3	4.55
7	2	1.39	0	0.00	2	2.86	7	1	0.72	0	0.00	1	1.52
8	0	0.00	0	0.00	0	0.00	8	1	0.72	1	1.39	0	0.00
9	0	0.00	0	0.00	0	0.00	9	2	1.45	0	0.00	2	3.03
10	0	0.00	0	0.00	0	0.00	10	1	0.72	1	1.39	0	0.00
PEP							HRV						
1	12	8.51	9	12.16	3	4.48	1	65	45.14	32	43.24	33	47.14
2	24	17.02	12	16.22	12	17.91	2	4	2.78	2	2.70	2	2.86
3	15	10.64	6	8.11	9	13.43	3	2	1.39	0	0.00	2	2.86
4	17	12.06	9	12.16	8	11.94	4	3	2.08	2	2.70	1	1.43
5	6	4.26	3	4.05	3	4.48	5	0	0.00	0	0.00	0	0.00
6	6	4.26	4	5.41	2	2.99	6	3	2.08	2	2.70	1	1.43
7	7	4.96	5	6.76	2	2.99	7	0	0.00	0	0.00	0	0.00
8	3	2.13	1	1.35	2	2.99	8	0	0.00	0	0.00	0	0.00
9	4	2.84	3	4.05	1	1.49	9	0	0.00	0	0.00	0	0.00
10	4	2.84	4	5.41	0	0.00	10	2	1.39	0	0.00	2	2.86

Recovery Intervals. In this approach, recovery was operationalized as the difference between physiological values during the last minute of the match and the first minute of the recovery phase. Positive emotions did not optimize recovery from game-related arousal for HR, PEP, CO, and HRV in terms of depth (i.e., greater reduction in cardiovascular activation) (see Table 11). Effect sizes were negligible to small. The differences in physiological measures between the match and recovery for the experimental and control groups are illustrated in Figure 9.

Figure 9

Mean Differences Between Match and Recovery for Experimental and Control Groups



Note. The plots display mean differences between raw values. Accordingly, as HR and CO decreased from the match to the recovery, the resulting differences are negative. Conversely, since PEP and HRV increased from the match to the recovery, the resulting differences are positive.

Table 11*Differences Between Experimental and Control Groups in Match-Recovery Cardiac Levels*

	Experimental Group		Control Group		<i>t</i>	<i>df</i>	Cohen's <i>d</i> [95% CI]
	<i>M</i> (<i>SD</i>)	Δ	<i>M</i> (<i>SD</i>)	Δ			
HR	80.33 (14.05)	-12.47	78.56 (11.84)	-10.93	1.21	100	0.24 [-0.15; 0.65]
PEP	102.86 (14.90)	4.96	103.90 (13.72)	6.53	0.61	91	0.13 [-0.28; 0.53]
CO	6.66 (1.36)	-0.53	6.48 (1.52)	-0.56	-0.16	85	-0.03 [-0.46; 0.37]
HRV	41.68 (18.19)	20.81	41.00 (16.04)	18.57	-0.70	68	-0.17 [-0.64; 0.30]

Note. Δ = mean difference from match phase. HR and CO decreased from the match to the recovery, while PEP and HRV increased from the match to the recovery.

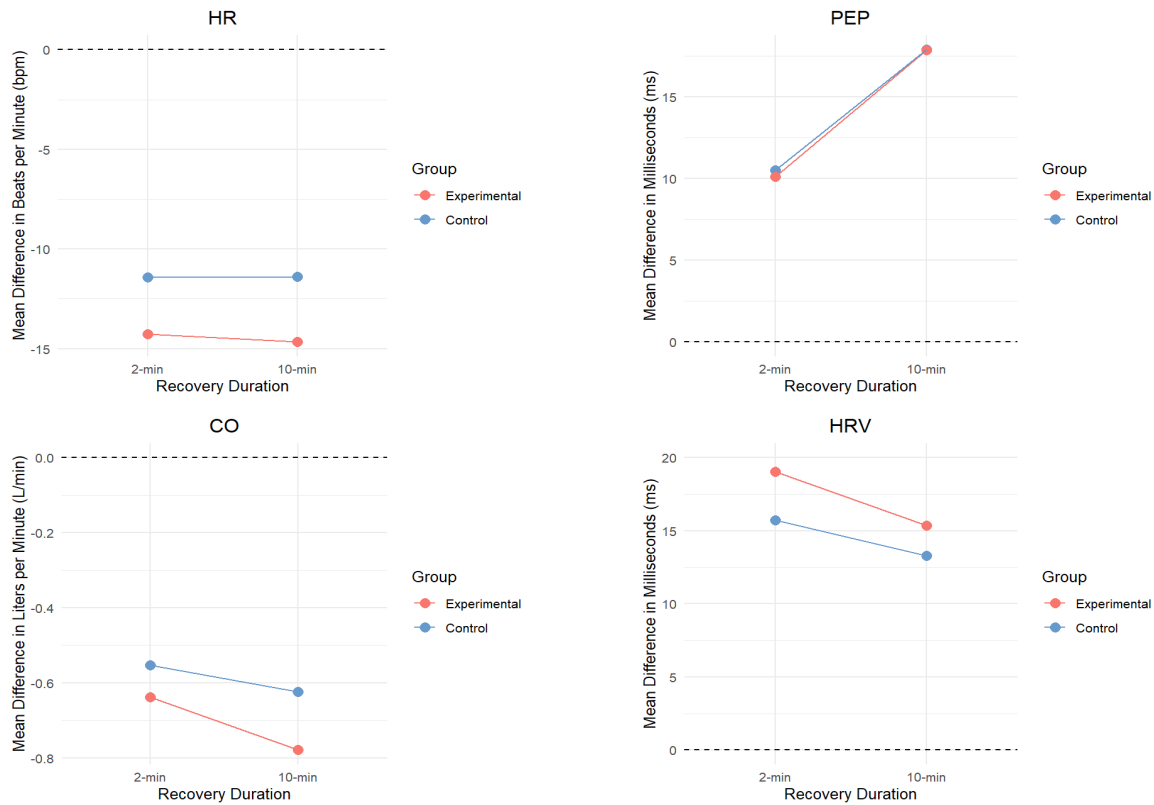
Additionally, to control for physiological activation at the end of the match, ANCOVAs were conducted with physiological values during the last minute of the match as covariates. The results revealed no significant differences in recovery between the experimental and control groups for (a) HR, $F(1, 99) = 0.65$; $p = .42$; $\eta^2_p = 0.01$; (b) CO, $F(1, 84) = 0.03$; $p = .86$; $\eta^2_p = 0.00$; (c) PEP, $F(1, 90) = 0.28$; $p = .60$; $\eta^2_p = 0.00$; and (d) HRV, $F(1, 67) = 0.43$; $p = .51$; $\eta^2_p = 0.01$. Effect sizes were small for HR and HRV. However, physiological activation at the end of the match was a significant predictor of recovery outcomes for (a) HR, $F(1, 99) = 13.42$; $p < .001$; $\eta^2_p = 0.12$ with medium to large effect size; (b) CO, $F(1, 84) = 4.97$; $p = .03$; $\eta^2_p = 0.06$ with medium effect size; and (c) PEP, $F(1, 90) = 44.75$; $p < .001$; $\eta^2_p = 0.33$ with large effect size, but not for HRV, $F(1, 67) = 0.22$; $p = .64$; $\eta^2_p = 0.00$. Gamers who exhibited higher physiological activation at the end of the match demonstrated greater decreases in HR, CO, and PEP during the first minute of recovery. However, this pattern likely reflects a natural physiological rebound effect rather than an undoing effect of positive emotions. HRV recovery was influenced by neither the study condition nor the level of physiological activation at the end of the match.

The recovery is a process and extending the recovery interval may provide a more comprehensive understanding of its dynamics. Therefore, additional analyses were conducted using two- and ten-minute recovery intervals. When the recovery interval was set to two minutes, positive emotions did not optimize recovery from esports-related arousal for PEP, CO, and HRV in terms of depth (i.e., greater reduction in cardiovascular activation). Effect sizes were negligible to small. However, a significant difference in HR was observed: gamers in the experimental group showed a greater decrease in HR compared to those in the control group with small to medium effect size (see Figure 10 and Table 12).

A similar pattern emerged when the recovery interval was extended to ten minutes. Positive emotions again did not optimize recovery from esports-related arousal for PEP, CO, and HRV in terms of depth (i.e., greater reduction in cardiovascular activation). Effect sizes were negligible to small. Nonetheless, a significant difference in HR persisted: gamers in the experimental group showed a greater decrease in HR compared to those in the control group with small to medium effect size (see Figure 10 and Table 12).

Figure 10

Mean Differences in Physiological Recovery in Experimental and Control Groups at 2- and 10-Minute Recovery Intervals



Note. The plots display mean differences between raw values. Accordingly, as HR and CO decreased from the match to the recovery, the resulting differences are negative. HR remained relatively stable throughout the recovery phase, while CO decreased progressively. Conversely, since PEP and HRV increased from the match to the recovery, the resulting differences are positive. PEP showed a consistent increase across the recovery phase, whereas HRV initially increased and then decreased again.

Table 12

Mean Differences in Physiological Recovery in Experimental and Control Groups at 2- and 10-Minute Recovery Intervals

	Experimental Group		Control Group		<i>t</i>	<i>df</i>	Cohen's <i>d</i> [95% CI]
	<i>M</i> (<i>SD</i>)	Δ	<i>M</i> (<i>SD</i>)	Δ			
HR							
2 min	78.47 (13.11)	-14.26	78.02 (11.20)	-11.43	2.25*	100	0.45 [0.05; 0.84]
10 min	78.09 (11.75)	-14.67	78.63 (10.85)	-11.39	2.33*	98.93	0.45 [0.06; 0.84]
PEP							
2 min	107.06 (13.38)	10.13	107.66 (10.79)	10.50	0.15	93	0.03 [-0.37; 0.43]
10 min	114.59 (11.30)	17.83	114.85 (9.05)	17.87	0.01	93	0.00 [-0.40; 0.41]
CO							
2 min	6.63 (1.39)	-0.64	6.49 (1.50)	-0.55	0.67	86	0.14 [-0.29; 0.57]
10 min	6.49 (1.22)	-0.78	6.42 (1.47)	-0.62	1.20	86	0.26 [-0.16; 0.68]
HRV							
2 min	42.85 (17.92)	19.04	38.16 (14.68)	15.73	-1.24	72	-0.29 [-0.74; 0.17]
10 min	39.68 (15.39)	15.36	37.65 (17.36)	13.31	-0.83	75	-0.19 [-0.64; 0.26]

Note. Δ = mean difference from match phase. HR and CO decreased from the match to the recovery phase, while PEP and HRV increased from the match to the recovery phase. For HR 10 min effect size Hedges' *g* was used due to violated homogeneity.

**p* < .05.

Non-parametric Testing. To address non-normality in the PEP (partial) and HRV (full), analyses were re-run using non-parametric methods. A non-parametric repeated-measures analysis with the Friedman test confirmed that gamers were physiologically engaged during the study; their PEP values significantly changed across the baseline, match,

and recovery, $\chi^2(5) = 281.54$; $p < .001$; Kendall's $W = 0.44$, indicating a moderate to strong effect size. Subsequent Wilcoxon signed-rank tests showed:

- A difference between the last minute of the baseline and the last minute of the prematch, $V = 5102.00$; $p = .02$; $r = 0.29$ [0.12; 0.44], indicating a moderate effect size; gamers showed higher PEP during the baseline compared to the last minute of the prematch.
- A difference between the last minute of the prematch and the first minute of the match, $V = 8194.50$; $p < .001$; $r = 0.83$ [0.78; 0.86], indicating a strong effect size; gamers had higher PEP during the last minute of the prematch compared to the first minute of the match.
- A difference between the last minute of the prematch and the last minute of the match, $V = 7111.00$; $p < .001$; $r = 0.67$ [0.56; 0.76], indicating a strong effect size; gamers had higher PEP during the last minute of the prematch compared to the last minute of the match.
- No difference between the last minute of the match and the first minute of the recovery, $V = 3211.00$; $p = .32$; $r = 0.20$ [0.04; 0.36], indicating a small effect size; gamers had lower PEP during the last minute of the match compared to the first minute of the recovery, but the difference was not statistically significant.

Comparisons between the experimental and control groups showed that gamers did not differ in their physiological responses from baseline to the match with negligible to small effect sizes. For PEP:

- baseline, $W = 2388.50$; $p = .26$; $r = 0.10$ [0.01; 0.28];
- first minute of prematch, $W = 2143.50$; $p = 1.00$; $r = 0.00$ [0.00; 0.20];
- last minute of prematch, $W = 2272.50$; $p = .56$; $r = 0.05$ [0.00; 0.23];
- first minute of match, $W = 2146.00$; $p = .99$; $r = 0.00$ [0.00; 0.20];

- last minute of match, $W = 2188.50$; $p = .84$; $r = 0.02$ [0.00; 0.18].

For HRV:

- baseline, $W = 1748.00$; $p = .20$; $r = 0.11$ [0.01; 0.28];
- first minute of prematch, $W = 1904.00$; $p = .60$; $r = 0.05$ [0.00; 0.22];
- last minute of prematch, $W = 1771.00$; $p = .24$; $r = 0.10$ [0.01; 0.28];
- first minute of match, $W = 2079.00$; $p = .75$; $r = 0.03$ [0.00; 0.21];
- last minute of match, $W = 1920.00$; $p = .66$; $r = 0.04$ [0.00; 0.23].

Similarly to parametric analyses, the main effect of the study phase was observed for experimental and control groups for both PEP, $\chi^2(4) = 241.45$; $p < .001$; Kendall's $W = 0.45$ (moderate to strong), and HRV, $\chi^2(4) = 126.44$; $p < .001$; Kendall's $W = 0.25$ (small to moderate), confirming that both measures significantly varied across the baseline, match, and recovery phases.

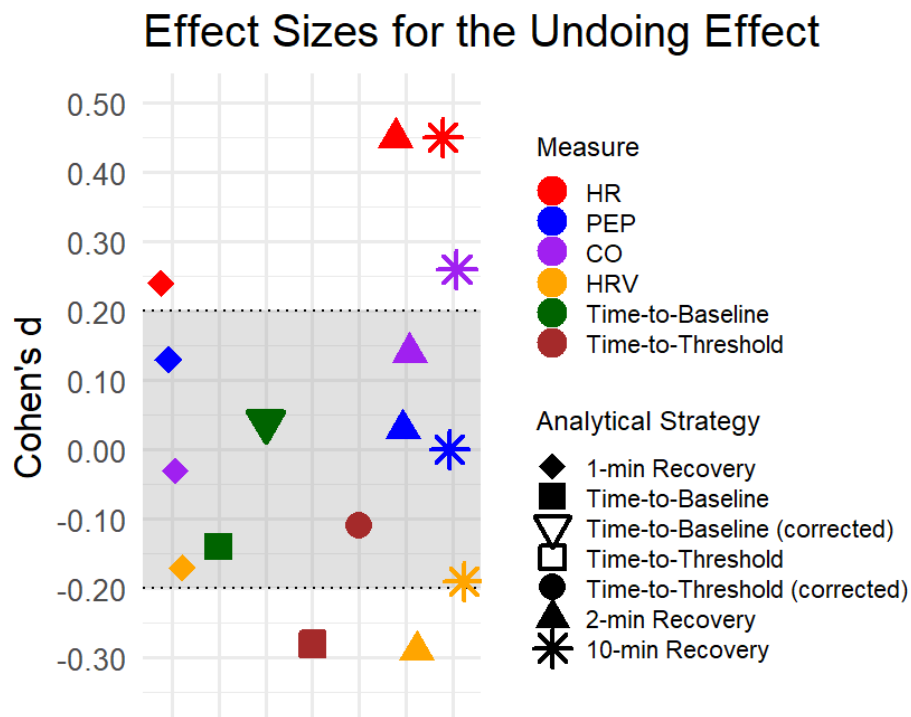
When testing whether positive emotions optimized recovery (i.e., produced greater reductions in cardiovascular activation), no significant group differences were found for either PEP or HRV, regardless of the recovery interval:

- one-minute recovery: PEP, $W = 1149.50$; $p = .55$; $r = 0.06$ [0.00; 0.28]; HRV, $W = 596.00$; $p = .89$; $r = 0.02$ [0.00; 0.27].
- two-minute recovery: PEP, $W = 1148.50$; $p = .79$; $r = 0.03$ [0.01; 0.24]; HRV, $W = 558.00$; $p = .17$; $r = 0.16$ [0.01; 0.38].
- ten-minute recovery: PEP, $W = 1138.00$; $p = .85$; $r = 0.02$ [0.00; 0.24]; HRV, $W = 587.00$; $p = .12$; $r = 0.18$ [0.01; 0.41].

Effect sizes ranged from negligible to small. Overall, the results of the non-parametric analyses were consistent with the parametric findings reported earlier. Parametric tests are generally robust to violations of normality and other assumptions (Norman, 2010). Therefore,

the non-parametric results were included as part of the multiverse analysis to improve transparency and aid in the interpretation of findings.

Summary of the Multiverse Analysis. The undoing effect was examined using a time-to-baseline and time-to-threshold approach, with adjustments for skewness. Additionally, a minute-based descriptive analysis was conducted to assess how many participants returned to baseline during each minute of the recovery phase. Recovery was also operationalized as the difference in physiological values between the match and various recovery intervals (i.e., the first minute, the first two minutes, and the full ten-minute recovery phase). Across these analyses, 18 effect sizes were calculated, ranging from -0.29 to 0.45, of which only two reached statistical significance. An additional six effect sizes were derived from non-parametric tests; none of these were statistically significant. In the primary analysis, two effect sizes were obtained: Cohen's $d = -0.14$ for time-to-IBI-baseline and Cohen's $d = -0.28$ for time-to-IBI-threshold. Taken together, the primary and multiverse analyses suggest that the undoing effect does not manifest in the esports context as a robust or consistent phenomenon across different operationalizations and analytical approaches. Figure 11 illustrates the variation in effect sizes based on the operationalization of the recovery.

Figure 11*Effect Sizes Across Analytical Strategies and Recovery Operationalizations*

Note. Dotted horizontal lines at $d = \pm 0.2$ indicate the threshold for a small effect size. Effects that are located within the $- 0.20$ and $+ 0.20$ area are considered negligible.

Chapter 8. Discussion

This study investigated the role of positive emotions in optimizing psychophysiological recovery following esports performance, specifically in terms of speed (i.e., faster return to baseline) and depth (i.e., greater reduction in cardiovascular activation). Using a multiverse approach, the analyses focused on the robustness of the undoing effect across various operationalizations of recovery and analytical strategies commonly employed in the undoing effect literature. Drawing on data from a psychophysiological experiment involving 144 gamers and 20 effect sizes, the results indicate that positive emotions did not optimize recovery - neither in terms of speed (i.e., faster return to baseline) nor depth (i.e.,

greater reduction in cardiovascular activation). These findings suggest that the undoing effect does not manifest within the esports context.

Findings

The present study investigated the undoing effect - defined as the capacity of positive emotions to accelerate physiological recovery from negative affect (Fredrickson, 2013; Fredrickson & Levenson, 1998) - within the esports performance context. It was hypothesized that positive emotions would optimize psychophysiological recovery following esports performance, specifically in terms of speed (i.e., faster return to baseline) and depth (i.e., greater reduction in cardiovascular activation). When applying time-to-IBI-baseline and time-to-IBI-threshold approaches, results showed that recovery occurred rapidly. In the time-to-IBI-baseline approach, gamers in the experimental group returned to baseline within 13 seconds, while those in the control group did so within 15 seconds. In the time-to-threshold approach, gamers in the experimental group returned to baseline within 4 seconds, while those in the control group did so within 6 seconds.

Further insights were gained through multiverse analysis. When recovery was defined as the difference in physiological parameters between the last minute of the match and the first minute of the recovery - no significant differences were found between the two groups. This results align with recent meta-analyses suggesting that the undoing effect is not consistently replicated (Cavanagh & Larkin, 2018; Behnke et al., 2023). Moreover, when the recovery interval was extended to two and ten minutes, no significant differences were found in physiological parameters between the two groups, except for HR: gamers in the positive emotions condition exhibited greater decrease in HR compared to those in the neutral condition.

Across both the primary and multiverse analyses, 20 effect sizes were calculated - ranging from -0.14 to -0.28 in the primary analysis and from -0.29 to 0.45 in the multiverse

analysis. Only two of these were statistically significant, suggesting that the undoing effect, in esports context, may be better understood as an artefact rather than a robust phenomenon.

Methodological Advancements

This study contributes to affective science by employing ICG to assess both stress reactivity and recovery in esports context. Sympathetic parameters such as PEP decreased during gameplay reflecting increased physiological mobilization, while parasympathetic markers like HRV increased during recovery, indicating a return to homeostasis. These physiological changes, measured through non-invasive techniques such as ICG, provide a reliable insight into ANS functioning (Seery, 2013). Given the limited use of ICG in positive emotion research (Behnke et al., 2023) and the scarcity of studies investigating HRV dynamics in esports (Sadowska et al., 2023), these findings offer valuable insights into the physiological processes underlying stress and recovery in competitive gaming.

This is among the first studies to explore the undoing effect using an esports tournament as an active and intense stressor - rather than passive tasks such as watching films or images. Gamers in this study experienced excitement before the match and physiological arousal during competition, corroborating previous research showing that esports elicits intense emotional and physiological responses (Behnke et al., 2020, 2024; Naidenova et al., 2024). The findings align with the sports psychology literature, which suggests that stress can be a positive experience for athletes, who often feel highly aroused yet positive before competitions (Peris-Delcampo et al., 2024).

A key strength of this study is its comprehensive application of multiverse analysis, which enhances the robustness and credibility of the findings by systematically examining different operationalizations of key variables and analytical strategies (Steege et al., 2016). The multiverse analysis included a) a time-to-baseline analyses with adjustments for data skewness; b) a minute-based descriptive analysis to assess how many gamers returned to

baseline during each of the ten minutes of the recovery phase; c) recovery operationalized as the difference in physiological values between the last minute of the match and various recovery intervals (i.e., the first minute, the first two minutes, and the full ten-minute recovery phase); and d) ANCOVAs to control for individual differences in physiological activation at the end of the match. This approach ensured that the findings were not influenced by specific methodological choices (Steege et al., 2016).

Measuring Recovery

Multiple recovery operationalizations were tested in this study, including both time-to-baseline and change score approaches. For the time-to-baseline analysis, ECG-derived IBIs were used. A moving average was calculated based on the current heartbeat and the five subsequent beats to estimate the precise duration of IBI recovery. A participant was considered to have returned to baseline once this moving average fell within the predefined baseline range and remained there for at least five consecutive beats (Fredrickson & Levenson, 1998). Two recovery operationalizations were applied: time-to-IBI-baseline-level and time-to-IBI-threshold (defined as the baseline mean IBI minus one standard deviation, as in Fredrickson & Levenson, 1998). Additionally, a minute-based frequency analysis was used to determine how many participants returned to baseline during each minute of the recovery phase

For the change score approach, recovery was defined as the difference between physiological values recorded during the last minute of the match and those during the first minute of recovery. Two extended recovery intervals were also examined (a) the average of the first two minutes and (b) the average of the full ten-minute recovery phase. These complementary approaches provided a more comprehensive understanding of recovery dynamics following esports performance. To date, no previous study has reported both change

scores and time-to-baseline measures within a single investigation, highlighting the methodological innovation of this work (Behnke et al., 2023).

While the time-to-baseline approach offers valuable insight into recovery dynamics, its interpretation in performance contexts warrants caution. In this study, the average HR during the last minute of the baseline was 82 bpm - substantially higher than the typical resting HR of approximately 60 bpm. This elevated baseline likely reflects anticipatory arousal related to the upcoming esports tournament rather than a true resting state (Mendoza et al., 2021; Schmidt et al., 2020; Sharpe et al., 2024; similarly in traditional sports context Moore et al., 2012, 2013, 2015; Souza et al., 2019). As a result, returning to this heightened “baseline” may appear faster, not necessarily due to more effective recovery, but rather because the physiological gap from peak arousal (match HR of ~94 bpm) is relatively small. Future studies should therefore consider baseline calibration and account for anticipatory stress when interpreting time-to-baseline as an indicator of physiological recovery in high-performance settings.

Moreover, the minute-based descriptive analysis highlighted a key limitation. In the context of esports performance, minute-based intervals may not provide sufficient temporal resolution for accurately capturing physiological change. Many participants returned to their baseline levels within the first two minutes of recovery, suggesting that physiological recovery can occur rapidly in this context. Notably, some gamers had already returned to baseline before the formal recovery phase began, further underscoring the need for more fine-grained, second-by-second measures to better capture the dynamics of recovery following esports performance.

By systematically testing various definitions and measurements of recovery, and by transparently reporting all results, this study offers a comprehensive evaluation of the undoing effect in esports context. The multiverse analysis enhances the reliability and generalizability

of the findings, demonstrating that conclusions regarding the undoing effect are not bound to a single methodological choice but are supported across multiple analytical frameworks (Steege et al., 2016).

Practical Implications

Regardless of their physiological advantages, positive emotions offer important psychological benefits, such as sustaining motivation in the face of setbacks, fostering passion, and promoting overall well-being (Seligman, 2011). Esports players may benefit from integrating mood-enhancing strategies - such as watching humorous film clips between rounds or engaging in lighthearted interactions with teammates - to alleviate tension following challenging matches. Coaches can also utilize humor during high-pressure moments (e.g., by sharing jokes or incorporating playful activities during breaks) to provide emotional support and strengthen team cohesion. Furthermore, incorporating mental health education into esports training programs could reinforce the connection between emotional well-being and performance, promoting a more holistic approach to player development. Importantly, humor can serve as a universal emotion regulation strategy that any player - regardless of competitive level - can use during challenging moments to benefit from the positive effects of positive emotions.

Behind the Thesis

One of the most compelling insights from this research lies not only in the empirical findings, but in the remarkable engagement of the gamers community. Despite the study taking place during the university exam period, over 400 players expressed interest and willingness to participate. This level of involvement underscores the passion and commitment of esports players and highlights their interest in the psychological aspects of performance. Participants consistently expressed appreciation for being treated as serious performers, rather than merely gamers. This reinforces the growing recognition of esports as a legitimate

performance domain, comparable to traditional athletic competition (Pedraza et al., 2020; Rambusch et al., 2007).

Moreover, the richness of data collected in esports contexts offers unique opportunities for affective science. The nuanced emotional and physiological responses captured during the competitive gameplay allow for in-depth exploration of emotion-performance relationships. For instance, researchers can examine how match outcomes influence recovery trajectories or how prematch emotional states may serve as buffers against stress during competition.

Finally, the findings suggest that esports tournaments can be deeply rewarding experiences - emotionally intense, yet overwhelmingly positive. Gamers reported experiencing excitement prior to the match and demonstrated heightened physiological arousal during gameplay, indicative of strong engagement and a positive orientation toward the competitive challenge. Esports thus emerges as a domain where passion meets personal growth, offering not only a competitive outlet but also opportunities for self-development, teamwork, and the cultivation of positive emotions, which are essential for well-being.

Limitations and Future Directions

Despite its contributions, the present study has several limitations. First, it focused exclusively on male CS2 players, which limits the generalizability of the findings to this specific performance context. Given that male players dominate first-person shooter games like CS: GO (Yee, 2016), including in Poland (Behnke, Stefańczyk et al., 2023), the gender imbalance in the sample reflects broader participation trends. However, as female involvement in esports continues to increase, future studies should explore affect-performance relationship in female and mixed-gender samples.

Additionally, the participants in this study were primarily recreational players with some competitive experience, rather than professional esports athletes. Future research should investigate recovery dynamics within professional esports settings where the stakes, demands,

and stress levels are considerably higher (Lies & Lautenbach, 2020). Moreover, the seated nature of esports gameplay entails minimal physical exertion. While this characteristic facilitates accurate physiological measurement, it may limit the applicability of findings - particularly those related to physiological responses - to other types of sports or performance contexts.

Second, although the study attempted to simulate a high-stakes environment by organizing a tournament with cash prizes, participants reported predominantly positive experiences before the tournament. This suggests that the expected stress may not have been sufficiently intense, thereby limiting the effectiveness of the positive emotions and inhibiting emergence of the undoing effect. Similar results were observed in the largest psychophysiological study in esports to date (Behnke et al., 2024). Despite prior evidence establishing esports as a valid stressor (Leis & Lautenbach, 2020; Naidenova et al., 2024; Sadowska et al., 2023; Smith et al., 2019), esports players typically report low-to-moderate pre-competition stress levels (Ferguson et al., 2016; Klier et al., 2022; Machado et al., 2022), comparable to those in traditional sports such as swimming (Rano et al., 2018) or judo (Obmiński & Mroczkowska, 2014). Pre-performance anxiety in esports also tends to fall within the medium range (Mendoza et al., 2021; Schmidt et al., 2020; Sharpe et al., 2024), aligning with findings from other athletic domains (Moore et al., 2012, 2013, 2015). Moreover, esports players often report more positive than negative emotions before gameplay (e.g., excitement, happiness vs. anxiety), mirroring trends observed in traditional sports (Turner et al., 2013).

It was expected that tangible rewards or punishments were not required to generate a motivated performance context - players may strive to win for personal satisfaction, to validate their skill, or to maintain social status within a team (Seery, 2013). However, the assumption that a laboratory tournament with monetary rewards would automatically evoke a

threat-type stress response may have been overly simplistic (Behnke et al., 2024).

Additionally, gamers often employ emotion regulation strategies, particularly by focusing on in-game tasks that help distract them from stress (Leis et al., 2021). Future studies should enhance ecological validity by incorporating additional stress-inducing elements common in esports, such as live streaming, comparisons to professional players, or public leaderboards (Sharpe et al., 2024; Smith et al., 2019; Tamir & Bigman, 2018). Ideally, data should be collected during actual tournaments to better capture authentic emotional and physiological responses.

Third, the amusement induction using film clips posed certain challenges. Although film clips are a well-established method for eliciting emotions (Joseph et al., 2020), their effectiveness may depend on the personal relevance of the stimuli. Emotional engagement is strongest when stimuli are meaningful to the individual (Lazarus & Folkman, 1987). In this study, the selected clips may have appeared outdated or irrelevant to the gamers population, reducing their impact. Participants may have cognitively recognized the humor without feeling genuinely amused. Moreover, because the clips were unrelated to gaming, they may have caused confusion rather than eliciting a coherent emotional response. Emotional responses to narrative-driven stimuli, such as film clips, typically unfold gradually, complicating the measurement of short-term emotional changes (Kaczmarek et al., 2021; Samson et al., 2016). This process may trigger a cascade of physiological activation and deactivation in response to the evolving plot - an effect observed in this study, as reflected in the physiological fluctuations illustrated in Figure 7 and Figure 9.

Although affect inductions are generally effective, their success varies depending on the induction type, target emotion, and participant characteristics such as gender (Joseph et al., 2020). Among positive affect induction procedures, story reading has been found to be the most effective, followed by viewing facial expressions. While films ranked fifth, they were

supported by the largest dataset and demonstrated consistent results (Joseph et al., 2020). The narrative structure of film clips makes them particularly suited for examining the temporal dynamics of emotion, which mirrors real-life emotional experiences (Samson et al., 2016). Emotional responses such as valence and approach-avoidance motivation typically require several seconds to differentiate from neutral states, making sufficient processing time essential in recovery studies (Kaczmarek et al., 2021). For instance, amusement and enthusiasm often peak around 100-120 seconds, whereas fear responses emerge quickly (within 30 seconds) but also diminish quickly (Kaczmarek et al., 2021). Future research should consider implementing continuous emotional monitoring and ensure that emotional stimuli are appropriately timed - meaning they align with the actual recovery period - so as not to miss their potential influence if recovery has already occurred. Additionally, stimuli should be tailored to the characteristics of the target population.

Fourth, clear physiological baselines and stress-level guidelines exist only for HR in the esports context (Andre et al., 2020; Behnke, Gross et al., 2022; Blom et al., 2019; Koshy et al., 2020; Machado et al., 2022; Moore et al., 2012; Zimmer et al., 2022). No such standards currently exist for PEP, CO, or HRV. Therefore, the outlier-exclusion approach based on physiologically implausible values were not used. Future psychophysiological studies should report descriptive statistics for these parameters to help establish normative data across different contexts and populations.

Conclusions

This study is the first to investigate the undoing effect within an esports context and to apply a multiverse approach to explicitly assess the extent to which the phenomenon is robust to different operationalizations of variables and analytical strategies. It offers a novel insights into psychophysiological recovery following esports performance. The findings suggest that, within this context, the undoing effect may reflect an artefact rather than a stable and

replicable phenomenon. Future research should continue to explore the physiological mechanisms underlying recovery to deepen our understanding of its role in esports.

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