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ORIGINAL PAPER

"Beating as one": the effect of coaches' behaviors on athletes' psychobiological wellbeing through the lens of self-determination theory

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Abstract

Self-determination theory (SDT) describes the influence of one's social environment on their well-being and development through the satisfaction or frustration of their psychological needs. This study investigates how athletes' perceptions of their coaches' behaviors influence their psychobiological health through psychological needs. By further integrating heart rate variability (HRV), a psychobiological marker of the autonomic nervous system balance, we further SDT-based research by providing a nuanced understanding of coaching behaviors' effect on athletes' chronic and acute stress responses. We used a daily diary design spanning two weeks of training and multilevel modeling to analyze data from 72 student-athletes. We found that perceptions of autonomy-supportive coaching behaviors led to greater overall need satisfaction, which then predicted engagement and prevented burnout. Perceptions of controlling coaching behaviors led to greater need frustration and, indirectly, increased burnout. At the between-individual level, perceptions of controlling coaching behaviors were associated with a greater increase in acute stress, while perceptions of autonomy-supportive behaviors were not. Our results entail that continuous exposure to controlling coaching behaviors can be detrimental to athletes' physiological system. Surprisingly, when coaching behaviors were held constant, need frustration was negatively associated with change in acute stress. Athletes reporting greater need frustration may disengage and show a blunt stress response, potentially reflecting a coping mechanism in response to need frustration. Our findings highlight the complex interplay between coaching behaviors, psychological needs, and autonomic nervous system balance within the SDT framework, deepening our understanding of athletes' experiences and promoting adaptive coaching strategies to foster their well-being.

Keywords Autonomy-supportive coaching · Controlling coaching · SDT's psychological needs · Heart rate variability · Acute stress response

Introduction

"I think our biggest strength is that he [the coach] finds a way to let […] us play with freedom. […] He just fills you with calmness and confidence before the game."—Jude Bellingham, Real Madrid player following the European Champions League quarter final win, April 2024.

"I have a to see a reason to put in this work and pressure on myself. If I lack purpose, I won't be stressed."—Former Canadian University football player.

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Focusing on the motivational mechanisms driving human behavior, Self-Determination Theory (SDT; Deci & Ryan, 1985; Ryan, 2023) is a well-established framework that captures the influence of one's social environment on psychological health (Deci & Ryan, 2000). Through the satisfaction, unfulfillment, or frustration of psychological needs (i.e., autonomy, competence, and relatedness), this theory highlights the factors in one's social environment that can facilitate or prevent well-being and optimal functioning (Deci et al., 2017).

SDT is particularly appealing in understanding leader-followers' interactions in newly formed teams, namely sports teams. Indeed, the coach is a main actor of the social environment within a team and plays a critical role in ensuring healthy and constructive interactions that nurture athletes' psychological needs and promote their well-being (Vallerand et al., 2008).

Psychological need satisfaction and frustration have been studied in relation to psychological outcomes such as engagement and burnout (Howard et al., 2024; Slemp et al., 2018), but less is known about their interplay with objective markers of acute stress in leader-driven teams. We argue that tackling this research gap is important for theory and practice. Knowing more about the acute stress responses of individuals in reaction to their leaders deepens our theoretical understanding of stress within SDT and complement findings on previously studied stress-related SDT outcomes such as perceived stress (Shannon et al., 2019), emotional exhaustion, or somatic symptoms (Olafsen et al., 2017). Investigating this model at different levels of analysis, namely the physiological, psychological, social and cultural levels, also portrays a broadened and deepened overview on how individuals respond to their social environment while displaying the interactions amongst these levels analysis of human behaviors (Sheldon et al., 2011). Practically, across the sport domain, relationships with coaches may be stress-inducing (e.g., see Zogg et al., 2024) and it is thus essential to understand how the complete stress response, including the acute and chronic components, unfolds to promote more favorable and healthy environments. Here, we address these issues by tackling the following research question: Why and how do athletes' perceptions of their coaches' behaviors influence their psychological health and physiological acute stress response?

Precisely, our work aims to extend SDT-based research by providing a refined understanding of coaching behaviors' influence on psychological well-being that distinguishes an individual's conscious and chronic stress response from their acute stress response. Theoretically, our work integrates acute stress into a model that captures stress-inducing relationships between coaches and athletes (Deci et al., 2017). Specifically, we conceptualize acute stress based on Oken et al.'s (2015) definition of stress as a neutral perturbation of the physiological system observed in response to environmental stimuli. This nuanced understanding of stress builds on previous findings presenting different psychobiological outcomes of being exposed to an autonomy-supportive or controlling leader (Bartholomew et al., 2011). Moreover, in doing so, we advance the psychological field's traditional reliance on self-reported data (Donaldson & Grant-Vallone, 2002) by integrating them with the psychobiological marker of heart rate variability (HRV; see Massaro & Pecchia, 2019). Specifically, HRV refers to the fluctuation in milliseconds between two consecutive heart beats and it indicates how well the human body can adapt and interact flexibly with the environment (Thayer & Lane, 2000, 2009). This approach offers a more objective and holistic analysis of how social environments impact athletes and aims to better understand the physiological effects of negative social dynamics, such as abuse and harassment in settings like sports (Zogg et al., 2024).

Self-determination theory's psychological needs

An important mini-theory of SDT, the basic psychological needs theory (Deci & Ryan, 2000), suggests that a person's well-being or development is altered as a consequence of whether their social environment satisfies, dissatisfies, or frustrates their psychological needs for autonomy, competence, and relatedness. The need for *autonomy* refers to feeling volitional and making one's own decisions and choices in line with one's values. The need for *competence* refers to the feeling of being efficient and in control of one's environment. Finally, the need for *relatedness* focuses on the meaningful and reciprocal relationships an individual shares with others (Deci & Ryan, 2000, 2002). Research in multiple life domains such as sports, education, work, and parenting has shown that psychological needs satisfaction leads to positive outcomes such as increased well-being, motivation, self-fulfillment, and productivity (Deci et al., 2017). In a variety of sports going from gymnastics to soccer, need satisfaction has been shown to be an important predictor of well-being (Gagné et al., 2003; Reinboth et al., 2004), but it also prevents negative outcomes such as burnout (Amorose et al., 2009). Hodge et al. (2009) have also shown that need satisfaction (mainly autonomy and competence) predicted behavioral investment and increased quality of the experience through their use of Schaufeli and Salanova's (2007) proposed measure of engagement. In contrast, when psychological needs are frustrated, negative outcomes including increased ill-being, negative affect or decreased performance are observed (Bartholomew et al., 2011; Van den Broeck et al., 2008). Specifically in the sports context, Warburton et al. (2019) examined how need satisfaction and

need frustration were simultaneously associated to well-being and ill-being. They found positive links between need satisfaction and well-being, and between need frustration and ill-being. They also suggested that experiencing need satisfaction can serve as a buffer to attenuate the effects of need frustration (Warburton et al., 2019).

Deci and Ryan (2000) further explain that positive outcomes are the result of healthy and autonomous regulatory processes and motives initiated by the social environment satisfying people's psychological needs. Frustration of psychological needs pushes individuals to develop defensive and controlling regulatory processes or find compensatory motives or needs substitutes, which may cause negative outcomes (Ryan et al., 2006; Vansteenkiste et al., 2020; Vansteenkiste & Ryan, 2013). In other words, satisfaction and frustration of the needs act as explanatory mechanisms that link a healthy social environment to greater functioning and well-being and a thwarting social environment to diminished functioning and ill-being, respectively.

Actors in the social environment: the role of coaches

Vallerand et al. (2008) highlighted the critical role of one's interaction with others in nurturing psychological needs, and, as a consequence, their well-being. In a team's dynamic, the leader plays an important role in modulating factors in the team members' psychosocial environment and ensuring a climate in which both performance and well-being can be optimized (Poucher et al., 2021). The interaction that an individual has with the person in the position of authority has a notable impact on their needs either being satisfied or frustrated. The leader may be the most direct contact for all members of a team, and thus the way they behave and how the members perceive their behaviors will impact on followers' psychological needs (Mageau & Vallerand, 2003). As described in Slemp et al.'s (2018) and Howard et al.'s (2024) meta-analyses, leadership influences can be studied in a variety of life domains, going from parental behaviors to academic education, work, and sports. Hence, leadership trends found in the literature are quite relevant when studying the influences of coaches' behaviors on athletes.

A key interpersonal factor that facilitates the satisfaction of individuals' needs for autonomy, relatedness, and competence is autonomy support[1] (Baard et al., 2004; Grolnick et al., 1991; Slemp et al., 2018). An autonomy-supportive coach is known to support the athletes' psychological needs while fostering their self-determined strivings (Vallerand et al., 2008) and nurturing their internal motivational resources (Slemp et al., 2018). The coach's behaviors create a climate of initiative, choice, support and understanding. Moreover, a coach adopting this leadership style is particularly interested in the opinions and viewpoints of athletes and offers opportunities for choice and contribution. This style also offers constructive and change-oriented feedback and avoids extrinsic rewards and punishments to foster their team's intrinsic motivation. Many researchers agree that these autonomy-supportive coaching behaviors lead to greater engagement, enhanced performance, and optimized psychological well-being (Baard et al., 2004; Bartholomew et al., 2011; Deci et al., 2001; Hardré & Reeve, 2009; Howard et al., 2024; Slemp et al., 2018).

Nonetheless, coaches can also display harmful or coercive behaviors (Bartholomew et al., 2010), either exclusively or alongside nurturing behaviors (Blanchard et al., 2009). In fact, behaviors such as abuse, harassment, ego-involvement, and dehumanization, are quite salient in the sports domain (Zogg et al., 2024). Such behaviors have been characterized as abusive or destructive (Ashforth, 1993; Brunet et al., 2015), yet they also portray psychologically controlling coaching behaviors. Specifically, destructive coaching is defined as the persistent display (or perceived display) of hostile verbal and non-verbal behaviors such as lying, threatening, intimidating members of the group, or expressing excessive anger toward one or many members of a group (Tepper, 2000). These destructive coaching behaviors, namely the belittling of the athlete, ego-involvement of the coach and non-contingent punishments (Brunet et al., 2015) are all consistent with controlling behaviors portrayed within the framework of SDT. With regards to belittling or diminution of the athlete, Bartholomew et al. (2010) suggest that using power-assertive coaching strategies designed to humiliate athletes are included in controlling behaviors and are expected to have harmful consequences on athletes' well-being. In coherence with Assor et al.'s (2002) and Barber's (2002) findings regarding children's dynamics with their teachers and parents respectively, taking credit for others' successes or attributing the athletes' achievements to the quality of one's coaching abilities are considered controlling behaviors that would hinder athletes' well-being. On its end, non-contingent punishment fits in the controlling strategies of providing controlling feedback and offering conditional regard (Ntoumanis, 2012). Qualitative research has shown that coaches dissatisfied with a loss can display complete indifference towards their athletes (Fraser-Thomas et al., 2009) or use guilt-inducing prompts to expression their disappointment (Krane et al., 1997). These contingent and conditional punishments can be detrimental to athletes' self-worth and well-being (Bartholomew et al.,

[1] Autonomy-supportive behaviors also include truly valuing the athletes and trusting their abilities. In theory, autonomy-supportive coaching behaviors are expected to support athletes' needs for autonomy, competence, and relatedness (Deci & Ryan, 2000). Some researchers opt for the use of "need-supportive" behaviors to refer to this construct. We use the term "autonomy-supportive" to remain coherent with the operationalization of our measured construct.

2010). In addition to being associated to a decrease in performance, increased dissatisfaction, stress, risks of depression and unhappiness (Lopez et al., 2020; Stirling & Kerr, 2009), these controlling coaching behaviors are expected to frustrate athletes' psychological needs (Bartholomew et al., 2010; Ntoumanis, 2012). A worrisome finding described in both Bartholomew et al.'s review (2010) and Ntoumanis' Chap. (2012) is that these behaviors can falsely appear to be adaptative as they can promote desired outcomes, namely increased engagement or performance, on the short term. It is important to point out that continued exposure to such behaviors can have important consequences on athletes' well-being on the longer term (Bartholomew et al., 2010).

Psychological needs as antecedents of engagement and burnout

In professional contexts, engagement and burnout are often used as indicators of well-being and ill-being (e.g., Bartholomew et al., 2011; De Francisco et al., 2018; Jowett et al., 2016). Engagement is defined as a pervasive cognitive and affective mind state that is fulfilling and positive, which has been conceptualized as the antithesis of burnout (Schaufeli et al., 2006). It encompasses vigor, absorption, and dedication, which respectively refer to one's level of energy, deep implication, as well as effort and pride (Schaufeli et al., 2006). At the opposite end of the psychological health continuum, burnout is characterized by physical and emotional exhaustion, devaluation of one's sport and a reduced sense of self-accomplishment (Eklund & DeFreese, 2015). Although distinct, these two indicators of psychological health can co-occur (Ryff & Keyes, 1995), which highlights the importance of studying them in conjunction.

Research has demonstrated a clear link between psychological needs satisfaction and engagement in individuals from various life domains (i.e., sports, work, education) and age groups (e.g., Bartholomew et al., 2011; Curran et al., 2014; Deci et al., 2017, Olafsen et al., 2017). Adie et al. (2008) studied the effect of autonomy-supportive coaching on psychological needs satisfaction, and consequently on well-being (i.e., vitality). Their cross-sectional study revealed that satisfaction of the needs for autonomy, competence, and relatedness separately predicted greater subjective well-being in sports participants. Bartholomew et al. (2011) replicated this positive and significant link between needs satisfaction and vitality in athletes. Bartholomew et al. (2011) extended their cross-sectional design into a daily diary study, which was able to capture the fluctuations of psychological states over two weeks, and found that well-being (i.e., positive affect in their study) was predicted by needs satisfaction daily, but also generally, while need frustration predicted burnout symptoms, depression, and negative affect (Bartholomew et al., 2011).

Acute stress responses to social environment

Various SDT-grounded researchers have examined the association between self-determined and controlled motivational components and different stress-related phenomena (Olafsen et al., 2017; Weinstein & Ryan, 2011). Broadly speaking, 'stress' describes the physiological and behavioral changes in the human system in response to an environmental stimulus (be it positive or negative), that perturbs the dynamic system of the human body (Oken et al., 2015). The stressor can range from competing in extremely bad weather to feeling excluded or neglected in a group (Oken et al., 2015). A positive environmental stimulus, such as winning a challenge or a competition, would also elicit a response from the human body and is thus also considered to be a stressor, albeit leading to positive feelings.

There are two main responses with regards to stress. *Acute stress* is a prompt physiological response to respond to a trigger or a discomfort. In contrast, *chronic stress* develops over time, when continuously or repeatedly being exposed to mental, physical, or emotional hazards (Hering et al., 2015). Short-term perturbations (i.e., acute stress) may benefit the system through the development of its long-term resilience to future stressors, yet continuous and repeated perturbations have a more important cost as they prevent the body and all its systems (i.e., cardiovascular, hormonal, etc.) to return to their baseline states (Oken et al., 2015). In addition to the physiological negative lasting effects, chronic stress symptoms include a variety of negative emotions including irritability, anxiety, depression, and anger (Hering et al., 2015)—which are often measured via self-reported measures (Schaufeli et al., 2006). Within the framework of SDT, chronic stress is often examined as an undesirable outcome that is positively predicted by needs frustration or controlled motivation (Bartholomew et al., 2011; Olafsen et al., 2017; Williams et al., 2014).

Acute stress responses are quite important to understand as their continuous activations lead to autonomic imbalance and poorer health, yet their punctual activation when exposed to a stressor can also take on an adaptative role and promote resilience for future events (Burke et al., 2005; Dickerson & Kemeny, 2004; Dienstbier, 1989). Interestingly, consistent with Lazarus' work on stress appraisal (Lazarus, 1999), acute stress responses are influenced by one's appraisal of the stressor. In the context of sports, Jones et al. (2009) explain through their Theory of Challenge and Threat States in Athletes (TCTSA) that an athlete perceiving having sufficient resources to go about their training would be in a *challenge* state whereas one perceiving lacking resource

to deal with the training would be in a *threat* state. Within the scope of SDT, Weinstein and Ryan (2011) have shown that autonomously motivated individuals are more likely to assess situations as challenges compared to externally motivated individuals. With regards to the physiological responses, *challenge* state is characterized by a quick activation of the autonomic nervous system in which energy is mobilized to take action and cope with the event (Epel et al., 2018) while *threat* state is portrayed with a slow activation of the autonomic nervous system that remains elevated for a longer period, thus representing a 'distress' in the system (Blascovich & Tomaka, 1996). In addition, findings from Texeira et al. (2015) suggest that acute stress responses may be influenced by individuals' chronic stress levels as they found that healthy chronically stressed males do not show an increased autonomic activity when exposed to a stressor. All those factors complicate the interpretation of acute stress, which highlights the pertinence of Bartholomew et al.'s (2011) suggestion to measure it using various indicators across different study designs.

Typically, acute stress responses are measured with psychobiological markers (Hering et al., 2015). Many researchers have already highlighted that self-reports should be complemented with psychobiological or hormonal parameters to grasp a more objective and holistic picture of individuals' states (Glenn & Raine, 2014; Romero-Martínez et al., 2022). Psychobiological markers are not subject to social desirability and offer information going beyond the individuals' voluntary control and awareness—such as cognitive and emotional regulation processes salient in challenging or stressful situations (Romero-Martínez et al., 2022). Although SDT research on acute stress responses is not abundant, researchers seem to agree that interpersonal interactions and the degree of self-determined motivation influence physiological reactivity (i.e., acute stress; Steel et al., 2021; Reeve & Tseng, 2011). For instance, Reeve and Tseng (2011) examined students' stress response when exposed to a controlling or an autonomy-supportive teacher in an experimental design and found that acute stress was increased in response to a controlling teacher, likely observed as a result of the fight-or-flight response of the autonomic nervous system (Jansen et al., 1995). To our knowledge, Bartholomew et al. (2011) were the first to examine the influence of need satisfaction and frustration on a psychobiological marker, namely the immunological protein S-IgA. They showed that need frustration was associated with elevated physiological arousal and emphasized the need to investigate SDT-related biological markers with a longitudinal design (Bartholomew et al., 2011). Similarly, Quested et al. (2011) examined the role of need satisfaction in cortisol responses to performance stress and found that higher need satisfaction was associated with lower cortisol responses.

Building on this emerging evidence, here we examine acute stress through measurements of HRV in a daily diary design spanning a two-week period. HRV captures the fluctuation in milliseconds (ms) between two consecutive heartbeats (R-R intervals) and reflects the activity of the autonomic nervous system over time (Shaffer et al., 2014). Specifically, the cardiovascular system responds to environmental stimuli by adjusting the balance of the parasympathetic and sympathetic nervous system—thereby influencing heart rate (Billman, 2011). Parasympathetic influences are essential for adapting appropriately to the various demands of the environment, and are "opposed" to sympathetic influences, which are responsible for alert situations and thus typically increase heart rate (Shaffer et al., 2014). Higher HRV reflects greater flexibility, adaptability, and parasympathetic dominance (Thayer & Lane, 2000, 2009).

To our knowledge, HRV has not been studied within the scope of SDT. Nonetheless, it has been shown in previous research that environmental stressors can cause perturbations in the human body, and thus HRV (Elovainio et al., 2006). For instance, Herr et al. (2019) found that individuals perceiving low organizational justice and lacking trust in their supervisor have lower HRV. Petrocchi and Cheli (2019) have also highlighted that environments promoting feelings of interpersonal and intrapersonal security are quite important to ensure adequate functioning of the parasympathetic nervous system. In fact, perceptions of interpersonal danger have been strongly associated to lower HRV (Petrocchi et al., 2017).

Multiple metrics can be derived from HRV data, such as the Baevsky Stress Index (SI) that was used and operationalized as acute stress in this study. The SI quantifies the degree of autonomic balance. Specifically, a higher SI indicates a shift towards sympathetic dominance and reduced variability, hence suggesting a stress response (Baevsky & Berseneva, 2008; Tarvainen et al., 2021). Conversely, a lower SI reflects greater parasympathetic activity and thus increased variability. In other words, while some measures of HRV are operationalized in a way in which higher scores reflect greater variability, higher scores of the SI measure of HRV indicate higher levels of stress (Baevsky & Berseneva, 2008). A unique advantage of HRV, in comparison with other indexes of acute stress (e.g., cortisol) is that it provides real-time, objective, and continuous data on individuals' states in response to an environmental stressor (Massaro & Pecchia, 2019). Indeed, this non-invasive measure has great sensitivity in capturing shifts between sympathetic and parasympathetic activity (Thayer & Lane, 2000, 2009).

The present study

The main purpose of this work is to further SDT-based research by providing a more nuanced explanation of how coaching behaviors influence one's psychobiological well-being by distinguishing their conscious and chronic stress response from their acute stress response. We achieved this through a novel scientific method that joins psychological needs with HRV, an objective psychobiological marker reflecting individuals acute stress response to their social environment.

We tested our conceptual model (see Fig. 1) in a sample of varsity athletes. Sport settings are well-suited for exploring the dynamics of fast-paced teams and relationships between leaders and team members (Day et al., 2012). Moreover, coaches play an important role in modulating environmental factors (e.g., training intensity, climate of training) and consequently often find themselves tasked with serving as catalysts for the development and well-being of athletes. Nonetheless, maladaptive behaviors or attitudes are also often observed in coaches, which highlights the importance of studying their psychosocial influences on athletes' health (Poucher et al., 2021; Zogg et al., 2024). Training in high-pressure environments may serve as a source of motivation for some athletes but potentially cause harm to the well-being of others (Baethge et al., 2020; Vaishali et al., 2020).

We investigated how and why athletes' perceptions of their coach's behaviors influenced, through SDT's psychological needs, their psychobiological health—the latter being assessed with measures of engagement and burnout as well as with acute stress measurements over two weeks of training. In coherence with the SDT literature (e.g., see Slemp et al., 2018), we expected autonomy-supportive behaviors to promote psychological need satisfaction (H_{1A}) and prevent need frustration (H_{1B}) while controlling coaching behaviors were hypothesized to reduce need satisfaction (H_{2A}) and increase need frustration (H_{2B}; see left end of Fig. 1). Moreover, perceived autonomy-supportive coaching behaviors were hypothesized to have a beneficial influence on athletes' well-being, specifically by predicting greater engagement (H_{3A}), lower levels of burnout (H_{3B}) as well as either stable or reduced acute stress responses (H_{3C}). We also hypothesized that perceptions of autonomy-supportive coaching would indirectly, through increased need satisfaction, influence engagement (H_{4A}), burnout (H_{4B}) and acute stress responses (H_{4C}). Perceived controlling coaching behaviors were expected to predict decreased engagement (H_{5A}), increased burnout (H_{5B}) and increased acute stress responses (H_{5C}). We also hypothesized that perceptions of controlling behaviors would indirectly, through increased need frustration, influence engagement (H_{6A}), burnout (H_{6B}) and acute stress responses (H_{6C}).

Methods

Participants

Our sample included 72 varsity athletes belonging to five teams from a large research-intensive Canadian university (see also "Data processing" section below for the total data point of the study). Our study was powered upon HRV, the novel variable included in SDT research. Quintana (2017) compiled and benchmarked HRV studies and suggested that a minimum of 61 participants were required to achieve a statistical power of 0.80 to detect a medium effect size, which corresponds to the median effect size across extant HRV studies. Two male teams and three female teams were

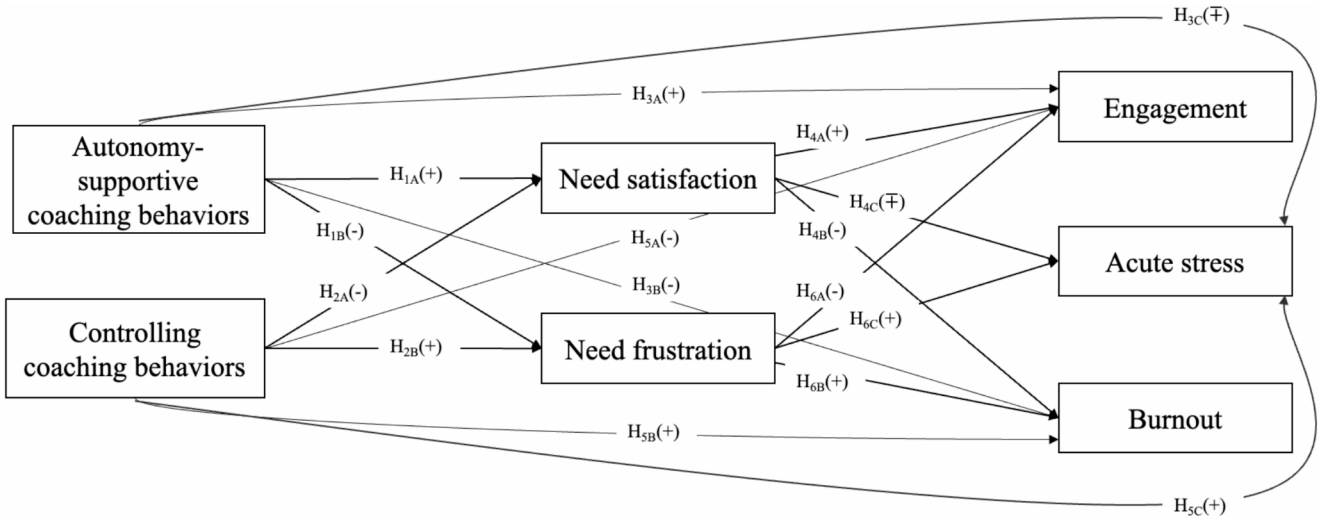

Fig. 1 Multilevel model examining the direct and indirect effects of coaching behaviors on engagement, burnout, and acute stress. H_4 and H_6 represent the indirect effects, via need satisfaction and need frustration respectively

included, and the average team size was $n = 14$. The sample mean age was $M = 22.06$ years old ($SD = 2.03$). 58.33% of participants were Caucasian, 33.32% were people of color, and 8.35% were from other ethnic groups. All participants were French speakers. Each team was newly formed, and data collection took place during their pre-season camp (i.e., intensive weeks of training in preparation for the upcoming competitions).

Procedure

All participants provided their informed consent before completing the measurements on the first training day[2]. A draw for one of three smartwatches was offered as an incentive for participation. Each team underwent continuous observation during an average of 9 consecutive training sessions spanning two weeks. Each participant was provided with a Polar Unite watch and a Polar H10 thoracic band, wearable and non-invasive tools able to record electrocardiogram signals (Polar Electro 2024, Kempele, FI; see Gilgen-Ammann et al., 2019), throughout the entire data collection. The accuracy, validity, and reliability of these instruments in measuring cardiac activity have been established through previous research (Schaffarczyk et al., 2022). Participants were instructed to take a 5-min measurement both before and 10 min after each training session. A researcher was present on-site to oversee and control the accurate execution of measurements, ensuring proper usage of the thoracic band by participants and adherence to the seated position and therefore a reliable signal acquisition.

Additionally, participants were asked to compile a 2-min online daily diary providing insights into their daily habits, such as their consumption of caffeine and/or alcohol and use of medications as well as documenting interactions with their coach during training. These diaries had two purposes: (1) priming participants to think of their coaches while taking their HRV measurements; and (2) gathering comprehensive information on factors that could potentially influence the study variables (Massaro & Pecchia, 2019). On the first, fifth, and final training days, they were asked to complete a 10-min online questionnaire (instead of the daily diary), which included questions regarding their perception of their coach's behaviors, their psychological needs, their levels of engagement, and their susceptibility to burnout risks (see the "Measures" section below). The questionnaire answered during the first training examined the global experience (i.e., baseline) of each participant since joining the team while the ones on the fifth and last training sessions reflected athletes' experiences of their past week of training. The completion of all three questionnaires was achieved by 96% of participants.

Data processing[3]

Self-reported data was collected through Qualtrics; HRV data was transferred to PolarCoach and exported to Kubios (Tarvainen et al., 2014) for data cleaning and HRV features extraction. HRV data treatment and cleaning procedures were performed based on the recommendations of the Task Force of the European Society of Cardiology and the North American Society of Pacing Electrophysiology (1996). Following data cleaning, we retained a total of 991 recordings (out of 1246) which each included an average of 394.79 beats (i.e., for a total of 390,454 datapoints for the current study). On average, data recordings cleaned from artifacts lasted 4 min and 37 s in which 7.61 beats were corrected.

Measures

Participants' demographic information was gathered during each team's first training and anthropometric measures (i.e., height and weight) were provided by the University's varsity program. Both demographic and anthropometric data served as control variables. Other controls including medication, caffeine, or alcohol intake were gathered daily.

Autonomy-supportive coaching behaviors

The Perception of Intrinsic Needs Support Scale (Moreau & Mageau, 2012, 2013) was adapted for sport and used to measure the perception of coaching behaviors facilitating the satisfaction of psychological needs. Specifically, we used the three subscales focusing on autonomy-supportive behaviors, which comprised nine items ($\alpha = 0.89$). The three behaviors examined include offering choices ($\alpha = 0.78$; e.g., "Within certain limits, my coach gives me the freedom to choose how and when I will execute my plays and my exercises"), explaining the reasoning behind requests ($\alpha = 0.76$; e.g., "I usually understand why my coach asks me to do or not to do something"), and being aware, accepting and acknowledging others' feelings ($\alpha = 0.75$; e.g., "My coach is open to my opinions and my point of view regarding work even when they are different from his/hers"). Participants were asked to indicate how much they agree with the statements presented on a 7-point Likert scale ranging from (1) "Strongly disagree" to (7) "Very strongly agree." A total score of autonomy-supportive coaching was created by averaging the score for each item.

[2] The study was approved by the university's Ethics Committee and was conducted following the principles of the Helsinki Declaration and is part of a wider pre-registered research effort that investigates HRV determinants of organizational behaviour.

[3] It is not possible to share research data publicly due to the sensitive nature of HRV data.

Controlling coaching behaviors

A French version of the Ashforth Measurement Instrument (Ashforth, 1987; Brunet et al., 2015) was used to measure athletes' perception of controlling coaching behaviors in their coach. This scale comprises 12 items (α = 0.90) asking athletes to rate various behaviors of their coaches. Although this instrument has been used in the literature to operationalize destructive or abusive types of leadership (e.g., see Ashforth, 1994), we specifically looked at behaviors indicative of a controlling coaching style consistent with SDT. The behaviors examined include giving non-contingent punishment (α = 0.84; e.g., "Often reprimands me without my knowing why"), belittling athletes (α = 0.81; e.g., "Exaggerates the importance of athletes' mistakes and weaknesses"), and demonstrating arbitrariness and self-aggrandizement (α = 0.80; e.g., "Takes credit for good work done by an athlete or by our team"). Respondents indicated how much they agree with the statements presented on a 7-point Likert scale ranging from (1) "Strongly disagree" to (7) "Very strongly agree." A total score of perceived controlling coaching was created by averaging the score for each item.

Psychological need satisfaction and frustration

A validated French version of the Psychological Need States at Work Scale (PNSW-S; Huyghebaert-Zouaghi et al., 2021) was adapted for sport and used to measure psychological needs satisfaction and frustration. The need satisfaction subscale is composed of 12 items (α = 0.93), with specifically three focusing on the need for autonomy (α = 0.83; e.g., "I feel free to make choices with regards to the way I train and perform"), six focusing on the need for relatedness (α = 0.91; e.g., "I feel valued as an important member of my team"), and three focusing on the need for competence (α = 0.85; e.g., " I am able to overcome challenges"). An aggregate score of the three subscales was used to build the composite variable of psychological needs satisfaction. The frustration subscale is composed of 13 items (α = 0.91), with four items looking at the need for autonomy (α = 0.70; e.g., "I feel forced to follow decisions about my training or my performance"), six items focusing on the need for relatedness (α = 0.89; e.g., "I feel excluded"), and three items examining the need for competence (α = 0.89; e.g., "I feel like a failure"). Participants indicated their degree of agreement on a 7-point Likert scale ranging from (1) "strongly disagree" to (7) "strongly agree." Similarly to the satisfaction of the needs, an aggregate score of the three subscales was used as psychological needs frustration.

Engagement

Engagement was assessed with a validated shortened French version of the Utrecht Work Engagement Scale which was adapted to the sport context (UWES-9; Schaufeli et al., 2006; Zecca et al., 2015). This scale includes three subscales looking at three indicators of engagement, namely vigor (α = 0.73; e.g., "When I get up in the morning, I feel like going to training"), dedication (α = 0.77; e.g., "My sport inspires me"), and absorption (α = 0.65; e.g., "I get carried away when I'm training"). Each subscale was composed of three items. Participants indicated how often they experience these feelings on a 7-point Likert scale ranging from (1) "Never" to (7) "Always." The total score for engagement was measured by averaging the score on the three subscales. Engagement was thus treated as a composite variable. Cronbach's alpha for this scale was α = 0.86.

Burnout

The validated French version of the Athlete Burnout Measure was used to measure athletes' level of exhaustion (Isoard-Gautheur et al., 2010). The scale includes 11 items that are divided into three subscales focusing on devaluation of the sport (α = 0.77; e.g., "I feel less concerned about being successful in my sport than I used to"), diminished sense of accomplishment (α = 0.82; e.g., "It seems that no matter what I do, I don't perform as well as I should"), as well as physical and emotional exhaustion (α = 0.83; e.g., "I feel emotionally wiped out from training"). The first two subscales were composed of four items while the latter encompassed three items. To avoid the ambiguity of physical fatigue following physical training, the items from the latter subscale were adjusted to emphasize emotional fatigue (rather than both physical and emotional fatigue). Respondents were asked to indicate how often they feel these emotions when thinking about their sport as a whole on a 7-point Likert scale ranging from (1) "Never" to (7) "Always." The total score for burnout was measured by averaging the score on the three subscales, hence treated as a composite variable. Cronbach's alpha for this scale was α = 0.76.

Acute stress

Each HRV recording was analyzed with the Kubios Standard HRV software (Tarvainen et al., 2014); multiple features from the time-domain and frequency-domain were extracted and then imported in a.csv file for statistical analyses. Our final variable of acute stress was measured using the change (or delta) in Kubios' SI computed via HRV's linear features. It is the square root of the Baevsky SI (Baevsky & Berseneva, 2008) formula shown below.

$$SI = \frac{AMo \times 100\%}{2Mo \times MxDMn}.$$

In this formula, AMo is the amplitude of the normalized R-R interval, Mo represents the median (in seconds) of the RR intervals, and MxDMn is the difference between the longest and the shortest R-R intervals. The square root of this formula is used to ensure a normal distribution (Tarvainen et al., 2021). Baevsky's SI is a geometric measure of HRV that illustrates the stress (intended as a perturbation in the system) the cardiovascular system is exposed to. Higher values of this index reflect reduced HRV and greater sympathetic cardiac activity. To also account for intra and interindividual variability, we computed ΔSI[4] (a difference score Post-Pre training) for every training session. This score illustrates the extent to which the SI of a participant varied during training and refers to the acute sympathetic nervous system activation. In simpler terms, this variable reflects how the system reacts spontaneously when exposed to the environmental stimulus (i.e., the coach's behaviors) and allows us to measure the construct of acute stress.

Statistical analyses

All data treatment was conducted using the R statistical language v4.2.2 (R Core Team, 2024). We conducted a multilevel path analysis in Mplus v8.6 (Muthén & Muthén, 2017). Specifically, athletes' daily acute stress responses and questionnaire entries were nested within individuals, and these individuals were then nested within their own team. This allowed us to conduct an integrative three-level path analysis examining the direct and indirect influences of coaching behaviors on psychological health and acute stress, through psychological needs. Nesting athletes within their specific team was done to accommodate the hierarchical structure of our data and ensure unbiased calculations for effect sizes and hypothesis tests at the lower levels of analysis (Hox et al., 2018). Robust standard errors were used for hypothesis testing. No model was tested at the between-cohort level of analysis since only five teams were sampled.

The indirect effects were computed as the product of two paths (MacKinnon et al., 2002), namely the path between the independent variable (e.g., autonomy-supportive coaching behaviors) and the mediator (e.g., needs satisfaction), and the path between the mediator and the outcome (e.g., engagement). All hypotheses were tested at the within-individual and the between-individual levels. The within-individual level examined the direct and indirect relations between our variables of interest within each participant across time while between-individual level examined the same relations between participants while controlling for their co-dependence associated to their specific team. To clearly separate and gather the 'pure' effects from our first two levels of analyses, that is, within-individual and between-individual effects (Hox et al., 2018), we have centered all our variables varying over time using the within-cluster centering method (Enders & Tofighi, 2007). Coffee intake was dummy coded (0 = No, 1 = Yes), and its effect on acute stress was controlled for at the within- and between-individual levels of analysis[5]. The daily acute stress baseline (i.e., recording pre-training) was also controlled for at the within- and between-individual levels of analysis. BMI and gender were added as controls[6] at the between-individual level. As suggested by Mändli and Rönkkö (2023), we included only the most relevant and influential control variables in our sample, which increased statistical power to detect pure effects, precisely by removing variability in acute stress that is due to external factors. Full-information maximum likelihood (FIML) was used to estimate our models while accommodating missing data and yielding greater statistical power (Enders, 2010).

Model fit was assessed by converging multiple indices, namely the Chi-Square test (χ^2), the Comparative Fit Index (CFI) and the Tucker-Lewis Index (TLI), the Root Mean Square Error of Approximation (RMSEA), and the Standardized Root Mean Square Residuals (SRMR). A fit is considered satisfactory when the χ^2 is not significant (Gefen et al., 2000), values of CFI and TLI are above 0.90 (Hoyle, 1995), the RMSEA and SRMR values are below 0.08, or even preferably below 0.06 (Caron, 2018; Hu & Bentler, 1999).

Results

Descriptive statistics

Table 1 presents the correlations at the within-level of analysis and intraclass correlation coefficients (ICC) for the between-individual level of all the variables used in the study. Table 2 presents the descriptive statistics and the correlations between all variables at the between-individual level of analysis as well as the ICCs for the between-cohort

[4] The ΔStress Index is a more complex and complete feature compared to other time-domain HRV features including mean heart rate, RMSSD (Root Mean Squared Standard Deviations of RR interval), and SDNN (Standard Deviation of NN intervals) or frequency-domain HRV features, namely high-frequency bands of HRV (HF-HRV). A correlation matrix of the ΔStress Index and other HRV features is presented in Appendix A.

[5] Alcohol intake ($M = 0.054$, $SD = 0.226$) and medicine intake ($M = 0.156$, $SD = 0.363$) were also measured, but were not included in the main analyses due to their extremely low prevalence in the sample studied.

[6] Age was excluded from the main analyses due to the homogeneity of the distribution.

Table 1 Correlation matrix and intraclass correlation coefficients of study variables at within-individual level of analysis

Variables	1	2	3	4	5	6	7	8
1. Autonomy-supportive coaching behaviors	–							
2. Controlling coaching behaviors	−0.307*	–						
3. Need satisfaction	0.464**	−0.345**	–					
4. Need frustration	−0.268*	0.515**	−0.600**	–				
5. Engagement	0.061	0.151	0.151	0.013	–			
6. Burnout	−0.014	0.184	−0.320**	0.220*	−0.206*	–		
7. Acute stress	−0.108*	0.031	0.014	−0.012	−0.093	0.040	–	
8. Coffee intake	0.005	−0.041	0.030	−0.014	0.139	−0.027	0.010	–
ICC	0.518	0.480	0.792	0.682	0.695	0.752	0.153	0.512

** $p < 0.001$, * $p < 0.05$

Table 2 Descriptive statistics and intraclass correlation coefficients of study variables at between-individual level of analysis

Variables	1	2	3	4	5	6	7	8	9	10
1. Autonomy-supportive coaching behaviors	–									
2. Controlling coaching behaviors	−0.571**	–								
3. Need satisfaction	0.728**	−0.448*	–							
4. Need frustration	−0.525**	0.490**	−0.814**	–						
5. Engagement	0.374**	−0.146	0.632**	−0.521*	–					
6. Burnout	−0.476**	0.391**	−0.683**	0.668**	−0.686**	–				
7. Acute stress	−0.155	0.319*	−0.051	−0.041	0.010	0.004	–			
8. Gender	0.210	−0.269	0.435**	−0.330**	0.347**	−0.288**	−0.297	–		
9. Coffee intake	−0.011	−0.035	−0.111	0.092	−0.178	0.173	0.022	−0.369*	–	
10. BMI	0.045	0.113	−0.006	0.089	−0.096*	0.233**	−0.002	0.024	0.005	–
ICC	0.144	0.187	0.013	0.013	0.026	0.006	0.091	–	0.094	–
M	4.728	2.346	5.061	2.585	5.517	3.296	5.396	0.431	0.372	23.141
SD	0.924	0.831	0.924	0.812	0.703	0.791	4.940	0.495	0.610	2.336

** $p < 0.001$, * $p < 0.05$. BMI refers to Body Mass Index

level of analysis. Intraclass correlation coefficients were estimated to determine whether there was substantial between-person variance in each time-varying variable and between-cohort variance amongst the main variables of the study. All ICCs at the between-individual level (see Table 1), except the one for acute stress, which was normalized, are above 0.48, suggesting that they mostly vary due to individual differences (i.e., at the between-individual level). These coefficients also depict that the self-reported variables are more stable over time compared to the acute stress, which appears to vary, for the most part, at the within-level. With regards to the ICCs at the between-cohort level (see Table 2), they suggest that respectively 14% and 18.7% of the variance in autonomy-supportive and coaching behaviors are due to cohort differences. The ICCs at both levels thus highlight the pertinence of accounting for the multilevel nested data structure in the analysis.

Direct and indirect effects of coaching behaviors over time

The multilevel path model showed an overall satisfactory fit ($\chi^2(37) = 95.29$, $p < 0.001$; CFI = 0.935; TLI = 0.850; RMSEA = 0.053; SRMR for pooled-within covariance = 0.047; SRMR for between-individual covariance = 0.122). Standardized estimates are shown in Fig. 2. At the within-level, perceived autonomy-supportive coaching positively predicted need satisfaction ($\beta = 0.396$, $p < 0.001$), yet its direct effects on need frustration ($\beta = -0.123$, $p = 0.165$), engagement ($\beta = 0.030$, $p = 0.792$), burnout ($\beta = 0.194$, $p = 0.144$), and acute stress ($\beta = -0.109$, $p = 0.231$) were not significant. Need satisfaction had a significant negative effect on burnout ($\beta = -0.379$, $p < 0.001$), but had no effect on either engagement ($\beta = 0.245$, $p = 0.075$) or acute stress ($\beta = 0.067$, $p = 0.116$). Perceived autonomy-supportive coaching had an indirect negative effect on burnout ($\beta = -0.150$, $p = 0.006$), through increased need satisfaction. The indirect effects of perceived autonomy-supportive coaching on engagement ($\beta = 0.097$, $p = 0.090$) and acute stress ($\beta = 0.027$, $p = 0.145$) were non-significant at the within-level of analysis.

Perceived controlling coaching behaviors positively predicted need frustration ($\beta = 0.477$, $p < 0.001$) and engagement ($\beta = 0.217$, $p = 0.026$), but had no direct effects on need satisfaction ($\beta = -0.223$, $p = 0.053$), burnout ($\beta = 0.122$, $p = 0.279$), or acute stress ($\beta = -0.063$, $p = 0.508$). Need

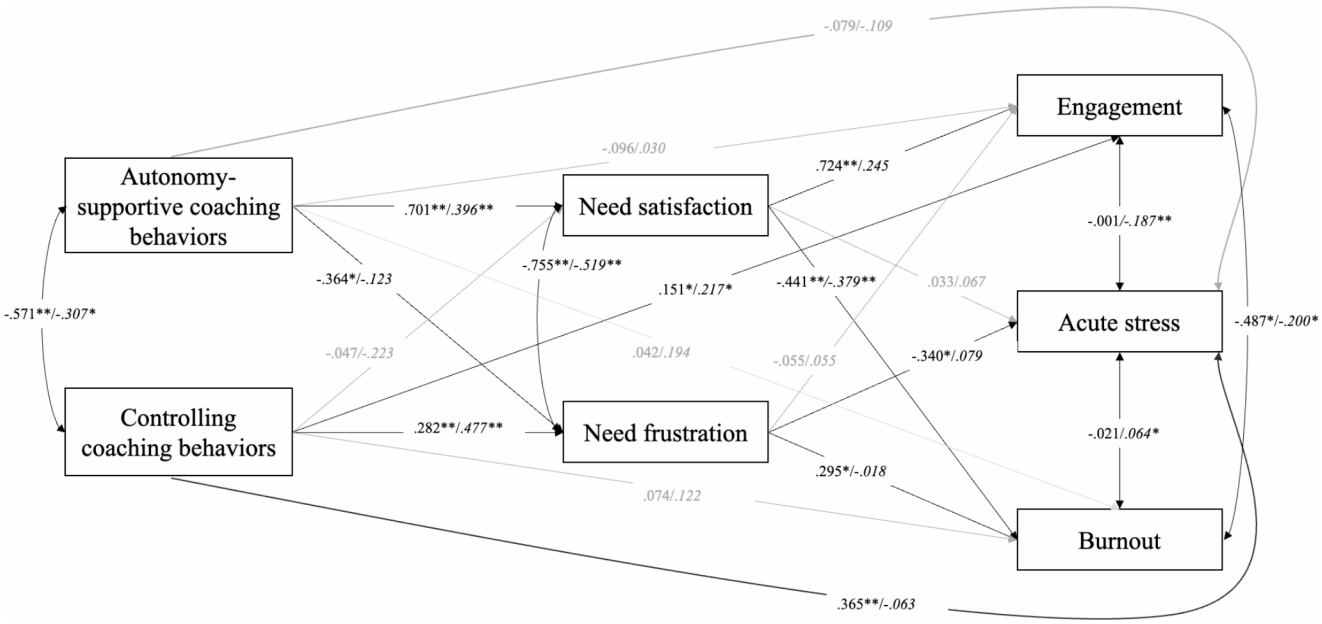

Fig. 2 Standardized estimates at the between-individual level / *Standardized estimates at the within-individual level*. **$p<0.001$, *$p<0.05$. Grey arrows represent links that are non-significant at both between-individual and within-individual levels of analysis

frustration had no direct effect on engagement ($\beta=0.055$, $p=0.155$), burnout ($\beta=-0.018$, $p=0.770$), nor acute stress ($\beta=0.079$, $p=0.214$). At the within-level, perceived controlling behaviors had no indirect effects on neither engagement ($\beta=0.026$, $p=0.202$), burnout ($\beta=-0.009$, $p=0.773$), or acute stress ($\beta=0.038$, $p=0.296$). With regards to the control variables, coffee was positively related to acute stress ($\beta=0.035$, $p=0.030$) and daily baseline of acute stress was negatively related to the increase in stress post-training ($\beta=-0.343$, $p<0.001$). Coaching behaviors accounted for 26.1% of the within-variance for need satisfaction ($R^2=0.261$, $p=0.004$), 27.9% of the within-variance for need frustration ($R^2=0.279$, $p=0.011$), 7.2% of the engagement within-variance ($R^2=0.072$, $p<0.001$), 13.7% of the burnout within-variance ($R^2=0.137$, $p=0.061$), and 13% of the within-variance for acute stress ($R^2=0.130$, $p<0.001$).

Direct and indirect effects of coaching behaviors across athletes

At the between-individual level, autonomy-supportive coaching positively predicted need satisfaction ($\beta=0.701$, $p<0.001$) and negatively predicted need frustration ($\beta=-0.364$, $p=0.002$), yet its direct effects on engagement ($\beta=-0.096$, $p=0.285$), burnout ($\beta=0.042$, $p=0.660$), and acute stress ($\beta=-0.079$, $p=0.234$) were not significant. Need satisfaction positively predicted engagement ($\beta=0.724$, $p<0.001$) and negatively predicted burnout ($\beta=-0.441$, $p<0.001$), but had no direct effect on acute stress ($\beta=0.033$, $p=0.684$). Through increased need satisfaction, autonomy-supportive coaching indirectly and positively predicted engagement ($\beta=0.508$, $p=0.003$) and negatively predicted burnout ($\beta=-0.309$, $p<.001$), yet had no indirect effect on acute stress ($\beta=0.023$, $p=0.681$). Although not included in our hypotheses, through prevention of need frustration, our results also suggest that perceived autonomy-supportive behaviors indirectly prevented burnout ($\beta=-0.107$, $p=0.022$).

Perceived controlling coaching behaviors positively predicted need frustration ($\beta=0.282$, $p<0.001$), greater engagement ($\beta=0.151$, $p=0.001$), and increased acute stress ($\beta=0.365$, $p<0.001$) but had no direct effects on need satisfaction ($\beta=-0.047$, $p=0.053$) or burnout ($\beta=0.074$, $p=0.279$). Need frustration positively predicted burnout ($\beta=0.295$, $p=0.001$) and negatively predicted acute stress ($\beta=-0.340$, $p=0.004$), yet had no effect on engagement ($\beta=-0.055$, $p=0.829$). Through increased need frustration, perceived controlling behaviors had a positive indirect effect on burnout ($\beta=0.083$, $p<0.001$) and a negative indirect effect on acute stress ($\beta=-0.096$, $p<0.001$). Precisely, perceived controlling behaviors have a positive effect on need frustration (*a* path: $\beta=0.282$, $p<0.001$), which has a negative effect on acute stress (*b* path: $\beta=-0.340$, $p=0.004$). The indirect effect on acute stress could be qualified as a competitive mediation (Zhao et al., 2010) as it points in the opposite direction of the direct effect of controlling coaching behaviors on acute stress (*c* path: $\beta=0.365$, $p<.001$). In light of this competitive mediation, our results revealed a positive total effect of controlling behaviors on acute stress ($\beta=0.461$, $p=0.024$). With regards to our control variables,

women showed greater acute stress responses ($\beta = -0.325$, $p = 0.002$), yet coffee intake ($\beta = -0.046$, $p = 0.495$), daily baseline of acute stress ($\beta = 0.017$, $p = 0.803$), and BMI ($\beta = 0.001$, $p = 0.992$) had no significant effect on acute stress. At the between-level of analysis, coaching behaviors accounted for 53.2% of the variance for need satisfaction ($R^2 = 0.532$, $p < 0.001$), 32.9% of the variance for need frustration ($R^2 = 0.329$, $p = 0.001$), 42.8% of the engagement variance ($R^2 = 0.428$, $p < 0.001$), 50.7% of the burnout variance ($R^2 = 0.507$, $p < 0.001$), and 23.9% of the variance for acute stress ($R^2 = 0.239$, $p = 0.040$).

Discussion

Rooted in the basic psychological needs mini-theory (Deci & Ryan, 2000), our study examined how autonomy-supportive coaching and controlling coaching behaviors impact athletes' psychobiological health, measured through engagement, burnout, and acute stress. Collectively, our work suggests that perceived coaching behaviors and psychological need states take on different roles. Precisely, perceived coaching behaviors are thought of as triggers of stress responses, acute or chronic (i.e., burnout), because of the directionality of the behaviors elicited in the items (e.g., "My coach often holds me responsible for things over which I have no control"). In contrast, need satisfaction and need frustration represent how athletes perceive their psychological needs to be nurtured or thwarted in their social climate (e.g., "I feel rejected").

Effects of coaching behaviors over 2 weeks of training

At the within-level, we found support for our prediction that athletes perceiving more autonomy-supportive behaviors in their coaches would have greater daily need satisfaction and, consequently, lower burnout levels. Inversely, our results also support our prediction that athletes perceiving more controlling coaching behaviors in their coaches would have greater need frustration over two weeks. These results are consistent with the general hypothesized model of SDT highlighting how autonomy-supportive environments can be beneficial for athletes' well-being (Howard et al., 2024) while need-thwarting environments are unfavorable (Bartholomew et al., 2011; Olafsen et al., 2017).

In contradiction with our prediction, we found that controlling coaching behaviors also predicted greater engagement over the two weeks of training. This finding is conflicting with the SDT literature emphasizing the negative outcomes associated with controlling coaching behaviors (Bartholomew et al., 2011). In their review of controlling coaching strategies, Bartholomew et al. (2009) highlight that such coaching behaviors can falsely appear to be adaptative as they may elicit the desired outcomes in the short term, yet their long-term consequences can be critical for athletes' well-being. Findings in our study reflect athletes' states at the very beginning of their upcoming seasons. The short-term phenomenon described in Bartholomew et al.'s (2009) review may thus be observed in our sample, where athletes were highly engaged (see overall mean score of $M = 5.57$ in Table 1) and were not negatively affected yet by their coach's controlling behaviors. This finding would likely be different if our study spanned over a longer period or if data collection happened at the end of the season. Another potential explanation for this result is that absorption, the subconstruct of engagement referring to one's deep implication in their sport, may be a function of controlling coaching behaviors (Zecca et al., 2015). Precisely, athletes may be absorbed in their sport—or have trouble disengaging from it– out of fear or guilt, in response to their coaches' controlling behaviors.

We found support for our prediction that autonomy-supportive coaching behaviors would not, directly nor indirectly, influence acute stress over time. We also found that controlling coaching behaviors did not have a direct nor indirect impact on acute stress over time. We believe that the length and the timing of our data collection, which lasted two weeks and took place at the very beginning of the season, both play an important role in understanding why results at the within-level of our analysis did not support some of our hypotheses. Considering negative impacts of stress are found mostly on a chronic basis, when one is exposed continuously and repeatedly to stressors, we could envision that variations in stress response could have been found in a design spanning a few months (Hering et al., 2015).

Effects of coaching behaviors across athletes

At the between-level, we found support for our prediction that individuals perceiving more autonomy-supportive coaching behaviors would report lower overall need frustration and greater overall need satisfaction, which in turn would be linked to greater engagement levels and lower burnout levels. In contrast with our predictions of direct effects, when need satisfaction is held constant, autonomy-supportive coaching behaviors did not influence athletes' engagement nor burnout levels. This emphasizes the important role of need satisfaction as a potential causal mechanism explaining how a nurturing coach can not only increase levels of engagement but also prevent burnout in their group (Slemp et al., 2018). In line with our prediction, we found that neither autonomy-supportive behaviors

nor need satisfaction predicted acute stress. Baumeister et al. (2001) suggested that individuals are more reactive to negative environmental stimuli compared to positive ones. In light of this, athletes not having greater or lower acute stress responses as a direct result of having an autonomy-supportive coach may be a 'normal' body reaction.

We also found support for our prediction that athletes perceiving more controlling behaviors in their coaches would report greater need frustration, and consequently greater levels of burnout. The non-significant direct effect of perceived controlling behaviors on burnout emphasizes the importance of psychological need frustration as a potential explanatory mechanism of the influence of controlling coaching on burnout, which has been suggested by many (e.g., see Bartholomew et al., 2011; Matosic et al., 2016). This result is coherent with previous findings suggesting that need frustration, resulting from high perceptions of controlling and tyrannical behaviors, leads to overall greater ill-being (Bartholomew et al., 2011; Trépanier et al., 2019). Our results shed light on how controlling coaching behaviors such as humiliating or criticizing athletes for no reason can have drastic consequences on athletes' psychological well-being, partly through the frustration of their psychological needs.

Contrary to our expectation, we found that athletes perceiving more controlling behaviors in their coaches reported greater level of engagement when all other predictors were held constant, and this link was not mediated by need frustration. This positive association between controlling coaching behaviors and engagement contradicts SDT's evidence-based postulates regarding the negative outcomes associated to a controlling social environment (Ntoumanis, 2012). As suggested by Bartholomew et al. (2009), this conflicting finding may be due to the timing of our data collection and the high levels of engagement of athletes regarding the upcoming season. It is therefore important to interpret them with caution and acknowledge that controlling behaviors such as diminishing an athlete or providing arbitrary punishments will likely have damaging effects on athletes' well-being over a longer period of time (Bartholomew et al., 2009).

Interestingly, at the between-level, we found support to our prediction that athletes perceiving more controlling behaviors in their coaches also would have overall increased acute stress responses when their need frustration is held constant. In other words, in a social environment held constant, controlling behaviors triggered greater acute stress responses in athletes. This result resonates with Reeve and Tseng's (2011) findings suggesting that students had greater acute stress responses when exposed to a controlling teacher. We argue that being exposed to controlling coaching behaviors may trigger an immediate perturbation in the system as these behaviors can be perceived as a direct attack to their person, making them feel diminished and thus leading their system to react with the infamous fight or flight stress response (Jansen et al., 1995; Jones et al., 2009). We have also found an indirect effect of perceived controlling behaviors on acute stress through need frustration, yet it points in the opposite direction of the direct effect and is thus qualified as a competitive mediation (Zhao et al., 2010). Precisely, in contrast with our initial prediction, the indirect effect revealed that athletes perceiving more controlling behaviors in their coaches reported greater need frustration and consequently decreased acute stress responses while controlling coaching behaviors directly led to increased acute stress responses. Although this conflicting indirect effect must be carefully interpreted, the significant positive association between need frustration and acute stress, while perceived controlling coaching is held constant, is not to be discarded. The blunt acute stress response could be explained by the athletes' detachment from their sport when their needs are frustrated (Balk et al., 2017). Disconnecting from sport demands from time to time is essential to remain physically and psychologically healthy, and this need is enhanced when the sport climate is unfavorable for the athlete (Balk et al., 2017). Although this should be further examined in future research, this blunt acute stress response may reflect athletes' detachment, portraying a coping response from the body in response to a thwarting environment.

Our SDT-based results also resonate with postulates from the TCTSA (Jones et al., 2009) and can be used together to further untangle the role of acute stress in our model. The latter suggests that when athletes have a low sense of self-efficacy and control and they assess not having sufficient resources to deal with the demands, they approach trainings as *threats* rather than *challenges* (Jones et al., 2009). Weinstein and Ryan (2011) proposed that individuals who are extrinsically motivated, typically as a result of having their psychological needs thwarted, experience a lesser sense of challenge compared to autonomously motivated individuals. We thus integrate these two arguments and propose that the psychological needs of autonomy, competence, and relatedness could serve as 'inner resources' to assess an environmental stressor as either a *challenge* (if satisfied) or a *threat* (if thwarted). A potential explanation for our results is that athletes reporting greater needs frustration may assess not having enough resources to take on their training and thus perceive it as a *threat*. With regards to the physiological reactions in such settings, athletes in a *threat* state typically show a slower rise in their sympathetic nervous system response that remains elevated for a longer period, which often represents a 'distress system' associated with a perception of harm (Blascovich & Tomaka,

1996). This slower activation of the system, which is more harmful to the human body, could explain the lower acute stress response observed in athletes with greater need frustration (Epel et al., 2018). In our sample, athletes reporting greater need frustration have a lower acute stress response, but higher levels of burnout, reflecting their experience of chronic stress. This trend is also coherent with findings from Texeira et al. (2015) suggesting that healthy chronically stressed males show no increase in autonomic nervous system reactivity when exposed to an acute stressor. Considering that Texeira et al.'s (2015) findings were only found in males, future researchers could clarify these empirical associations in both males and females.

To illustrate the findings of acute stress responses, we suggest thinking of the sport settings as the savannah. If we assess having sufficient resources to survive in this environment, we would likely take on the adversities in the savannah as challenges, which would require quick acute responses at given times, but our system would habituate and go back to its normal state quickly. If we assess not having sufficient resources (portraying need frustration), we would likely be chronically on edge, and all events—perceived as threats—would elicit a slower rise in our sympathetic response with a maintained activation over time. However, regardless of our accessible resources, if we were to run into a hungry lion (portraying a controlling coach), our survival mode would likely be activated and this activation would be seen, in part, in our quick sympathetic activation, which equates to high acute stress responses in our study.

Theoretical contributions

An important theoretical contribution of our work is the proposition of the nuanced role of stress within the SDT framework. Acute stress responses are often not under our awareness and control and thus can provide objective information regarding our bodily reactions to nurturing or thwarting psychosocial settings (Romero-Martínez et al., 2022). Our findings portray the functioning and dynamics of a complex system– information that cannot be provided with the use of scales. Moreover, by capturing the real-time dynamic interplays between the sympathetic and parasympathetic branches of the autonomic nervous system, our findings complement previous evidence of coaching behaviors on other biomarkers such as cortisol levels (Reeve & Tseng, 2011) or immunological protein S-IgA (Bartholomew et al., 2011). By answering the need to integrate multiple levels of analysis when studying human functioning (Sheldon et al., 2011), our study extends knowledge on psychobiological well-being by integrating four levels of analysis. Precisely, our use of HRV as an index of acute stress portrays the nervous system activity, our self-reported measures of engagement and burnout reflect the conscious clinical psychology state, the perceptions of coaching behaviors depict the influence of social relations and our focus on the sports setting presents the cultural influences of a varsity program. Integrating these four levels of analysis from Sheldon et al.'s (2011) multilevel perspective upon human behaviors provides a broadened overview of coaches' influences on athletes' well-being and psychobiological functioning.

Moreover, in both theory and practice, a negative connotation is associated to the construct of stress. While continuous and repeated exposures to stressors (i.e., chronic stress) can hinder good functioning of bodily systems (Oken et al., 2015), acute stress responses can have beneficial long-term implications as they mobilize individuals' mental resources when facing threats in their social environment and promote resilience to future challenging events (Dickerson & Kemeny, 2004; Dienstbier, 1989). In this study, acute stress is framed as a neutral perturbation of the physiological system observed in response to environmental stimuli (Oken et al., 2015). Being exposed directly to controlling behaviors can thwart an athlete and elicit an acute stress response instantly. This finding highlights and provides further evidence that continuous exposure to a controlling coach would eventually prevent proper functioning of an athletes' bodily systems by overactivating the sympathetic nervous system, thus preventing balance of the autonomic nervous system (Oken et al., 2015). Future research should investigate the lasting effects of controlling coaching behaviors on athletes' HRV through a study design spanning over several months.

The unexpected blunt acute stress response associated with need frustration further emphasizes the need to integrate biomarkers to have a broadened understanding of athletes' response to their coaches' behaviors and their social environment. By integrating acute stress in our conceptual model stemming from SDT, we found an unexpected association with need frustration that should be further explored. In coherence with Balk et al. (2017), we argue that this negative link between need frustration and acute stress could be explained by the athlete's detachment from their sport, portraying their body's coping response when exposed to a thwarting environment. Another potential explanation entails that psychological needs may serve as 'inner resources' that could influence their appraisal of an environmental stimulus and consequently influence their acute physiological reaction. Both athletes' detachment mechanisms and cognitive appraisal of trainings should be considered in future studies to validate these potential avenues.

Furthermore, our study provides further evidence that coaches can display autonomy-supportive and controlling behaviors simultaneously, just like athletes can report need satisfaction and need frustration simultaneously. For instance, our results suggest that the same coach can

provide their athletes with choices during practice, which would partly satisfy psychological needs, while also overly criticizing some athletes and thus frustrating those athletes' psychological needs. Although opposite, these constructs are not mutually exclusive (Blanchard et al., 2009) and our findings highlight that both the lighter and darker side of social contexts must be included in research studies and theoretical frameworks to examine a more complete portrait of psychosocial influences on human functioning.

Methodologically, our daily diary research design is, to our knowledge, the first to investigate how the behaviors of coaches can impact athletes' acute stress responses, through the satisfaction and frustration of their psychological needs. Decades of SDT-based research has shown the positive outcomes that psychological need satisfaction have on individuals' functioning and well-being (Ryan, 2023). Our daily diary design, which combines self-reported psychological health measures with HRV, an objective psychobiological marker of acute stress, allows us to extend the positive outcomes to individuals' biological functioning. Our thoracic wearables are unobtrusive and allow to gather real-time, objective, and continuous data on individuals' states in response to a stressor– thus providing unparalleled insights into social environment influences and enriching traditional metrics such as self-reported questionnaires. This methodology adds considerable validity and relevance to SDT amongst other motivational theories as it provides evidence of how social environments influence, through motivational mechanisms, one's acute stress response.

Practical contributions

From a practical perspective, results from our study not only highlight environmental conditions promoting athletes' development and well-being but also specify behaviors that coaches should adopt or avoid to fuel this optimal psychosocial environment. Our design may shed greater light on harassment and abuse issues found in sport environments, and thus emphasize the importance of implementing SDT-based training designed for coaches to: (1) help them recognize the (often unintentional) influence of their controlling behaviors on athletes, and (2) teach them how to be a lever for their team and engage in behaviors that promote their psychological needs for autonomy, competence, and relatedness. Coaches are often blamed for their behaviors when they are simply not equipped to provide an autonomy-supportive environment. The practical aim of our work is to promote interventions that will provide them with sufficient tools to build optimal environments for their athletes. Prospectively, our findings may also be relevant to other fast-paced environments in which leaders are subject to adopt autonomy-supportive or controlling behaviors, such as the corporate world.

Limitations and future research

Our study is not without limitations. First, there are missing data that are due to the study design. Indeed, the use of the full questionnaire during only three (out of the nine) trainings implied that some variables were only measured at the end of a training week rather than at the end of each training. Moreover, noncompliance from few athletes was observed from the researcher who was on-site during data collection, which led to the exclusion of additional HRV recordings. These two sources of missing data may impact the statistical power of the study, yet their effects were mitigated with the use of the FIML estimation in our main analyses. Although no between-cohort effects were tested, the small number of teams included in our third level of analysis also constitutes a limitation. Other analyses were considered, namely a two-level analysis with fixed effects for each team. Adding four fixed effects largely complexified our model and did not allow for generalization of our findings to other teams (McNeish & Stapleton, 2016). In light of these limitations, our three-level model remained the most theoretically and statistically sound alternative. Robust standard errors were used for hypothesis testing to prevent instability in our results. Another limitation of our design is that, except for the Athlete Burnout Measure (Isoard-Gautheur et al., 2010), all of our scales were adapted and used in the sports setting, yet they have not yet been validated in this new context. Hence, future research could aim to validate the adapted scales to the specific context and population represented by athletes. Similarly, given the unexpected link with need frustration, future SDT researchers could examine the relation between need unfulfillment, being the more passive need state ranging between need frustration and satisfaction (Huyghebaert-Zouaghi et al., 2021), and acute stress. Furthermore, while athletes included in this study did not all share the same coaching staff, they all came from the same varsity program in the same university and were sampled during the same academic year. This entails that they are all exposed to the same organizational culture (e.g., same university budget for sports) and thus possibly limits the generalizability of the findings. Future research should recruit participants from other diversified backgrounds (i.e., different universities, different countries) to replicate results in different social settings. Lastly, as described in the results section, our daily-diary design showed a lack of variation within participants across the span of two weeks, suggesting that future research should extend the current design over even longer periods of time.

Conclusion

In conclusion, this work integrates the perception of coaching behaviors, psychological need satisfaction and frustration, well-being, and acute stress within the well-established framework of SDT. It does so by joining HRV measures, reflecting acute stress responses, with self-reported data, and thus providing an objective and nuanced understanding of how coaching behaviors influence athletes' psychobiological health. Our findings highlight the pivotal role of autonomy-supportive behaviors in fostering athletes' health while reporting the detrimental effects of controlling coaching behaviors. Furthermore, the unexpected relationship between need frustration and acute stress provides a nuanced understanding of how the psychosocial environment can influence individuals' physiological responses. Our findings resonate with our two opening quotes in that allowing athletes to be free and autonomous in their sport truly encompasses beneficial outcomes including giving them a purpose to give it their all. These insights deepen our comprehension of the role of stress within SDT, but also have practical implications for enhancing coaching practices.

Appendix

See Table 3.

Table 3 Correlations between ΔStress index and other HRV time- and frequency-domain features

Variables	1	2	3	4	5
1. ΔStress Index	–				
2. ΔMean heart rate	0.610*	–			
3. ΔRMSSD	−0.489*	−0.622*	–		
4. ΔSDNN	−0.662*	−0.635*	0.897*	–	
5. ΔHF-HRV	−0.208*	−0.402*	0.838*	0.695*	–

SDNN Standard deviation of NN intervals, *HF-HRV* high-frequency bands of HRV

* $p < 0.001$. *RMSSD* Root mean squared standard deviations of RR interval

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Data availability It is not possible to share research data publicly due to the sensitive nature of HRV data.

Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content nor the authorship of this article.

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