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New methodological, intervention and neuroscientific perspectives in sports psychology, volume II

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New methodological, intervention and neuroscientific perspectives in sports psychology, volume II

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Editorial: New methodological, intervention and neuroscientific perspectives in sports psychology, volume II

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Editorial on the Research Topic
New methodological, intervention and neuroscientific perspectives in sports psychology, volume II

This Research Topic presents contributions that expand the frontiers of Sport Psychology, addressing new methodological, intervention, and neuroscientific perspectives. The articles included encompass a broad range of approaches and emerging perspectives, spanning from conceptual research to innovative empirical studies.

At a conceptual level, most articles focus on the relationship between personality variables and sports practice. Several studies delve into the examination of anxiety and insomnia in athletes and their impact on performance. From a methodological standpoint, various investigations employ Mixed Methods, integrating questionnaires with observational techniques, along with neuroscientific tools such as electroencephalography (EEG) and eye-tracking, providing deeper insights into cognitive and emotional processes in sports.

Neuroscience plays a crucial role in this volume, with articles examining the neurophysiological correlates, with fMRI, to investigate brain activity in sport practices such as Baduanjin. A neuropsychological approach is also employed to predict pre-competition anxiety and enhance intervention strategies in high-performance settings.

Through the application of advanced statistical tools and software such as SPSS, JASP, and EEGlab, these studies contribute significant methodological richness, offering valuable resources for future research and interventions in sport psychology. Collectively, these works provide a comprehensive and up-to-date perspective on the latest trends in the field, with the potential to enrich our understanding of mental and emotional processes in sports.

This volume reflects the dynamic evolution of the discipline, and we hope it serves as a valuable resource for both researchers and practitioners interested in sport psychology and its practical applications.

To provide a comprehensive overview of the contributions included in this volume, we present a summary based on different criteria:

1 Conceptual scope

Majority of the articles (11) are original research, one focuses on a protocol (Luo et al.), and one is strictly conceptual in nature (Tossici et al.). This Research Topic includes reference works exploring personality variables and their relationship with sports practice (Pineda-Espejel et al.), including tactical decision-making in basketball (Díaz-Rodríguez and Pérez-Córdoba) and gym-goers' behavior (Tavares et al.). Some studies analyze personal motivation and emotion, examining their relationship with academic performance and sports practice (Fierro-Suero et al.). Other focus on methodological aspects, comparing self-perception and observational methodologies in handball (Prudente et al.). Several contribute to scale validation studies in Chinese athletes, specifically on anxiety (Zhang et al.) and non-clinical insomnia (Tan et al.), or in Spanish-speaking Mexican athletes through the validation of the Interpersonal Behavior Questionnaire (IBQ) (Pineda-Espejel et al.). Finally, several articles incorporate a neuroscientific perspective, examining the relationship between sports skills and cognitive/emotional functions through direct neural activity recordings (Carey et al.; Wang et al.; Yu et al.). Additionally, one study proposes a protocol for neuroimaging research (Luo et al.), while another focuses on neuropsychological aspects of sports performance (Caramés et al.).

2 Methodological

The empirical studies included in this Research Topic demonstrate different procedural orientations. The majority use questionnaires, either exclusively (Fierro-Suero et al.; Pineda-Espejel et al.; Tavares et al.; Tan et al.; Zhang et al.) or in combination with other methodologies (Caramés et al.; Díaz-Rodríguez and Pérez-Córdoba; Prudente et al.; Yu et al.), including mixed-methods framework (Prudente et al.).

Additionally, one study employs structural equation modeling (Fierro-Suero et al.), while another incorporates standardized tests (Díaz-Rodríguez and Pérez-Córdoba). Three studies primarily focus on adapting questionnaires for different athlete populations, including Chinese athletes (anxiety: Zhang et al.; non-clinical insomnia: Tan et al.) and Mexican athletes (Interpersonal Behavior Questionnaire – IBQ: Pineda-Espejel et al.).

Some studies incorporate cognitive or practical tasks (Caramés et al.; Carey et al.; Wang et al.; Yu et al.) in combination with neuroscientific techniques, such as electroencephalography (EEG) (Carey et al.; Wang et al.; Yu et al.) and eye-tracking (Carey et al.).

This Research Topic includes various software tools and analytical methods relevant to sport psychology.

Regarding software, the studies utilize SPSS, JASP (Carey et al.), and R (Zhang et al.) for statistical analysis. Eye-tracking tools such as ASL X6 Mobile Eye Tracker and EyeVision (Carey et al.) are also employed, along with observational platforms like Lince, SDIS-GSEQ, and Hoisan (Prudente et al.). Neuroscientific research incorporates NeuroScan NuAmps, EEGlab for MATLAB (Yu et al.), ANT Neuro, BioTracer+, and Nexus-10 (Wang et al.). Other specialized platforms include MENPAS (Caramés et al.), REDCap (Tavares et al.), and Mpus (Fierro-Suero et al.; Pineda-Espejel et al.).

The statistical and analytical methods used encompass *t*-tests (Díaz-Rodríguez and Pérez-Córdoba; Fierro-Suero et al.; Yu et al.), ANOVAs (Carey et al.; Yu et al.; Wang et al.), and MANOVAs (Wang et al.). Regression models (Díaz-Rodríguez and Pérez-Córdoba; Fierro-Suero et al.; Zhang et al.), correlation matrices (Díaz-Rodríguez and Pérez-Córdoba; Caramés et al.), and Spearman correlations (Caramés et al.; Prudente et al.) are also applied. Psychometric evaluations include Cronbach's alpha (Caramés et al.; Tan et al.), McDonald's omega (Prudente et al.; Pineda-Espejel et al.; Tan et al.), and confirmatory factor analysis (Pineda-Espejel et al.). Neuroscientific analyses focus on EEG signal processing (Carey et al.; Yu et al.; Wang et al.), power spectrum analysis (Wang et al.), and independent component analysis (Carey et al.; Yu et al.). Additionally, some studies implement machine learning techniques, such as decision trees using CHAID (Tavares et al.).

This Research Topic presents a diverse set of methodologies, statistical techniques, and neuroscientific tools applicable to sport psychology, providing valuable insights for future research and interventions in the field.

3 Scope of application

Articles published in this Research Topic present a particular focus on personality factors influencing physical activity (Díaz-Rodríguez and Pérez-Córdoba; Fierro-Suero et al.; Pineda-Espejel et al.; Tavares et al.), with some studies applying these concepts to specific sports, such as basketball (Díaz-Rodríguez and Pérez-Córdoba). Others examine neurophysiological correlates of specific sport tasks, including golf (Carey et al.; Yu et al.), or sport-related skills such as visuomotor ability (Wang et al.).

In addition, a mixed-methods approach is used to increase data reliability, applied to specific situations in handball (Prudente et al.). The neuropsychological approach is also employed to predict anxiety in athletes prior to sporting events (Caramés et al.). Furthermore, three articles focus on the adaptation or validation of questionnaires for use with Chinese athletes (anxiety questionnaire, Zhang et al.; non-clinical insomnia, Tan et al.) or Mexican athletes (IBQ, Pineda-Espejel et al.).

This Research Topic also includes a conceptual work that focuses on the Psiconeuroendocrinological (PNEI) approach to stress phenomena in sports performance, providing a holistic perspective (Tossici et al.). Moreover, a protocol is presented for implementing fMRI in sport psychology, specifically in the practice of Baduanjin (Luo et al.).

In summary, we highlight the contributions of the 13 articles published in this Research Topic and offer them to our readers, with the hope that they will help expand knowledge in this field.

4 Conclusions

The articles included in this Research Topic provide a comprehensive range of theoretical and methodological contributions. As editors, we are pleased to present these works and their valuable transfer to the scientific community.

The articles in this volume have garnered significant attention, as evidenced by their high number of views, according to internal metrics. All of the articles were published between 2023 and 2024. Of the 26 articles initially submitted, 13 were ultimately accepted, yielding an acceptance rate of 50%.

This Research Topic reflects the evolving landscape of Sport Psychology, and we are confident that it will make a substantial impact in advancing knowledge and informing future research in the field.

Author contributions

AH-M: Writing – original draft, Writing – review & editing. MA: Writing – original draft. VM-S: Writing – original draft, Writing – review & editing. JC: Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Reliability and validity of the Chinese version of the Athens insomnia scale for non-clinical application in Chinese athletes

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Purpose: This study aimed to revise and examine the reliability and validity of the Chinese version of the Athens Insomnia Scale for Non-clinical Application (AIS-NCA) among Chinese athletes. Additionally, the study tested the scale in non-athlete individuals with similar sleep management practices to further analyze its cultural specificity among Chinese athletes and make preliminary inferences about its applicability in other Chinese populations.

Methods: Four hundred twenty-six Chinese professional athletes and 779 high school students participated in this research. Both athletes and students were divided into two parallel groups for exploratory and confirmatory factor analyses. Additionally, three athlete samples and one student sample were established for reliability and validity assessments. Among athletes, the Pittsburgh Sleep Quality Index, the Epworth Sleepiness Scale, the Athlete Sleep Screening Questionnaire, and the Warwick-Edinburgh Mental Well-Being Scale were employed to evaluate convergent and discriminant validity. Re-test reliability was evaluated at intervals of 1 and 2 weeks. In the case of students, convergent and discriminant validity were tested using the Pittsburgh Sleep Quality Index and the General Self-Efficacy Scale, with re-test reliability assessed at two-week intervals.

Results: The Chinese version of the AIS-NCA consists of six items, categorized into two dimensions: sleep problems and daytime functioning. This structure explained 65.08% (athletes) and 66.22% (students) of the variance. Confirmatory factor analysis revealed good model fit, with values of $\chi^2/df = 2.217$, CFI = 0.975, AGFI = 0.929, TLI = 0.953, and RMSEA = 0.076 among athletes, and $\chi^2/df = 3.037$, CFI = 0.979, AGFI = 0.947, TLI = 0.961, and RMSEA = 0.072 among students. The scale demonstrated a reasonable degree of measurement invariance. The overall scale and two subscales exhibited strong reliability and validity among athletes. Similar results in terms of reliability and validity were also observed within the student sample.

Conclusion: The Chinese version of the AIS-NCA shows promise as an assessment tool for evaluating the sleep quality of Chinese athletes. It effectively captures both sleep-related concerns and daytime functionality within the athlete population. The scale demonstrates solid reliability and validity in professional athletes and holds potential for application across various other demographic groups in China.

KEYWORDS

AIS-NCA, athlete, non-clinical, sleep problem, daytime functioning

Introduction

Sleep is widely acknowledged as a fundamental component of human health (Buysse, 2014). Adequate sleep is essential for individuals to accomplish personal and professional responsibilities effectively. This is particularly crucial for athletes, as they rely on sleep as a critical method for fatigue recovery (Halson, 2013; Malhotra, 2017; Bonnar et al., 2018). Research has demonstrated that sleep quality is linked with cognitive development, recovery from cognitive impairment or fatigue, and injury recovery for athletes (Chennaoui et al., 2021; Leong and Chee, 2022; Cook and Charest, 2023). Conversely, poor sleep quality or sleep deprivation hinders recovery from fatigue and impairs athletic performance, increasing susceptibility to sports injuries (Gupta et al., 2017; Dwivedi et al., 2019; Charest and Grandner, 2022; Cook and Charest, 2023). Athletes and coaches have recognized the importance of sleep in enhancing athletic performance and have integrated it into their training and event planning (Venter, 2014; Walsh et al., 2021).

Research investigating sleep quality in professional athletes has indicated suboptimal sleep quality in this population (Gupta et al., 2017; Kölling et al., 2019). Athletes' sleep quality may be inferior to that of the general population due to stress, training fatigue, or other factors related to training and competition (Lastella et al., 2018; Fullagar et al., 2019; Lastella et al., 2020; Vitale et al., 2022; Halson et al., 2022a,b). These observations, along with the need for enhanced athletic performance, have spurred research aimed at analyzing and intervening to improve athletes' sleep quality characteristics (Bonnar et al., 2018; Dunican et al., 2019; Gwyther et al., 2022; Vitale et al., 2022). Consequently, the assessment of sleep quality among athletes and the implementation of interventions have become critical topics in the field of sports science.

In sports science research, the measurement of sleep quality is crucial when analyzing athletes' sleep patterns and implementing interventions (Halson, 2019). Scales are the most widely used approach to evaluate sleep quality in research. Studies examining athletes' sleep quality, identifying factors influencing sleep quality, and implementing interventions, such as Cranial Electrotherapy Stimulation and sleep hygiene, have primarily relied on scales, such as the Pittsburgh Sleep Quality Index (Van Ryswyk et al., 2017; Kwon et al., 2019; Driller et al., 2022; Suppiah et al., 2022; Monma et al., 2023). While these scales have facilitated significant advancements in sleep quality research among athletes, their limitations and potential biases should not be overlooked.

Specifically, most scales face the critical question that they were originally designed to aid in clinical diagnosis or to meet other clinical needs for sleep measurement (Buysse, 2014; Mollayeva et al., 2016; Sattler et al., 2021). The question of whether sleep scales developed for clinical diagnosis or other clinical needs are applicable to athletes who do not experience insomnia or have suboptimal sleep quality remains unresolved. Furthermore, it is noteworthy that the positive aspects of sleep are increasingly gaining attention (Buysse, 2014). The traditional focus of sleep medicine on sleep disorders and deprivation has proven inadequate, and the mere absence of disease is no longer considered sufficient to meet the present-day demands on sleep (Buysse, 2014). Therefore, it is uncertain whether the use of clinical sleep scales can effectively evaluate sleep quality among athletes in non-clinical settings, and their ability to provide reliable insights into athletes' sleep beyond clinical considerations is questionable.

Several studies have revealed the limitations of sleep scales, which are commonly used in sports science research and practice. For instance, Driller and colleagues utilized the Pittsburgh Sleep Quality Index to compare sleep differences among athletes in different sports but found no differences in the overall PSQI score (Driller et al., 2022). However, when the scores of some of the questions were analyzed, they revealed differences between sports. The breakdown of PSQI components to describe sleep is common in such studies (Gupta et al., 2017; Bender et al., 2018a,b; Driller et al., 2022; Romdhani et al., 2022; Halson et al., 2022a,b). It may serve as a compromise between the scale and the population. Additionally, a review of studies on sleep quality problems in athletes found that the PSQI may not capture some sleep issues that occur in certain cases (Gupta et al., 2017), raising doubts about the validity of clinical scales for non-clinical patient studies.

To address this gap, Sattler and colleagues have developed a sleep scale for non-clinical use, called the Athens Insomnia Scale for Non-Clinical Application (AIS-NCA; Sattler et al., 2021). They noted that most sleep questionnaires used in current research are primarily intended for clinical use, screening populations, and then identifying individuals with sleep disorders for diagnosis or intervention. While these measurement tools are essential for clinical purposes and can help with diagnosis and intervention, there is a greater need in practice for a scale that can more precisely reflect the severity of sleep problems, daytime functioning, and other relevant factors. Such a scale would be helpful in studies with a preventive purpose. Additionally, the scale should be short and concise and adaptable to specific populations or limited measurement time, depending on the study's needs, particularly in studies that require a large number of scales to be completed within a limited time to analyze factors that could play a preventive role.

AIS-NCA arose from this background and need (Sattler et al., 2021). The scale was adapted from the Athens Insomnia Scale (AIS), which has been shown to be a useful substitute for the Pittsburgh Sleep Quality Index (Kawaratani et al., 2022). Due to its excellent quality, the AIS was chosen as the starting point for developing a sleep scale suitable for non-clinical settings.

Specifically, the AIS-NCA introduced several modifications to the original AIS: (1) Some items were rephrased to increase the versatility. (2) The 4-point scale was replaced with a 5-point scale, enhancing measurement precision and facilitating the identification of differences in sleep quality among non-clinical populations. (3) The response options for each item were rewritten to balance positive and negative states, making them better suited for describing sleep characteristics in non-clinical populations. As a result, the AIS-NCA consists of seven items, each scored on a five-point scale, with all items categorized into two dimensions: sleep problems and daytime function. For a timeframe of 1 year and 1 month, the AIS-NCA demonstrated good reliability and validity (Sattler et al., 2021). Since its release, researchers have employed the scale in studies of medical staff during the COVID-19 pandemic (Reicherts et al., 2022), offering a constructive means to evaluate sleep quality in these workers. Moreover, the scale has been utilized in large-scale investigations concerning the effects of risk exposure and prognosis on sleep during the pandemic, leading to the proposal of recommendations for improving sleep quality based on the findings (Zerbini et al., 2022), thereby providing scientific support for public health promotion strategies during this challenging time.

It should be emphasized that the AIS-NCA is not intended to replace existing tools but extends their utility for non-clinical purposes. The AIS, being an excellent insomnia screening tool, has been employed in both clinical and non-clinical individuals studies, demonstrating high diagnostic validity in differentiating between the two groups (Soldatos et al., 2003; Chiang et al., 2009; Chung et al., 2011). However, these studies used the AIS primarily as a screening tool for identifying insomnia disorder, as it was initially designed (Soldatos et al., 2003). For non-clinical people, particularly groups like athletes who prioritize sleep health and its impact on athletic performance, the focus is not solely on identifying sleep disorders but rather on measuring and describing changes in sleep quality itself. Assessing the extent of positive or negative sleep quality is crucial for them, rather than exclusively concentrating on more extreme negative situations. This approach aligns with the emphasis on evaluating sleep quality in the context of sleep health (Buysse, 2014). The enhanced generalizability and balanced evaluation in AIS-NCA are intended to complement the AIS, catering to this specific need.

A similar situation is observed in the realm of sleep measurement tools for athletes. The Athlete Sleep Screening Questionnaire (ASSQ) is the sole available screening tool explicitly designed to assess athletes' sleep quality (Samuels et al., 2016). The primary purpose of this questionnaire is to determine the need for further screening, diagnosis, or intervention among athletes, focusing on screening and intervention recommendations (Samuels et al., 2016; Gouttebarge et al., 2020). The sleep difficulties subscale within the ASSQ holds particular significance, as users rely on critical thresholds to identify athletes with potential sleep quality issues, warranting intervention. However, the emphasis on screening for sleep problems restricts the broader application of the ASSQ in daily training assessments and research involving athletes, especially in the context of sleep quality as a novel approach to enhancing athletic performance. This further emphasizes the necessity of applying AIS-NCA to the athlete population.

In summary, AIS-NCA offers a new perspective and methodological supplement for assessing athletes' sleep quality. Although the Athlete Insomnia Screening Scale (AIS-NCA) has been studied for public health or disease prevention purposes and has shown good validity and practical value (Sattler et al., 2021; Reicherts et al., 2022; Zerbini et al., 2022), there is still a lack of research on its use in athletes. In recent years, researchers have recommended the use of scales that are specifically designed for athletes to evaluate sleep and account for some of the unique characteristics of athletes (Samuels et al., 2016; Rabin et al., 2020). Therefore, before using the AIS-NCA in the athlete population for non-clinical purposes, it is necessary to revise and test the scale's validity and reliability in athletes.

Moreover, it is crucial to highlight that the AIS-NCA functions as a self-report scale. Sleep quality lacks a universally agreed-upon definition (Harvey et al., 2008), implying that individual perceptions of sleep inherently shape its structure, particularly within self-report scales. This suggests that the structure of the AIS-NCA among Chinese athletes may be influenced by two main factors: Chinese culture and the athletic profession. Regarding the former, previous research using the widely utilized Pittsburgh Sleep Quality Index (PSQI) has already unveiled slight variations in its structure across different countries, even among similar university student populations (Gelaye et al., 2014). Chinese cultural influences on Chinese athletes could manifest in specific characteristics within the scale's structure. As for the latter, studies investigating the structure of the PSQI among diverse populations have identified considerable variability (Manzar et al., 2018), including among Chinese student populations, where distinct structures have been observed among adolescents and university students (Guo et al., 2016; Guo, 2022). This implies that the AIS-NCA's structure and validity characteristics among Chinese athletes may also be associated with their athletic profession. Therefore, examining the potential influences of cultural and occupational/population factors is imperative during revising and testing the AIS-NCA among Chinese athletes. While this examination will not impact the applicability of AIS-NCA among athletes, such expansion holds significant promise for future cross-group and cross-cultural comparative research. Additionally, it can offer preliminary insights for applying AIS-NCA among other Chinese populations, thus laying the groundwork for methodological approaches in future cross-group and cross-cultural comparative studies.

This study aimed to revise the Chinese version of AIS-NCA among Chinese athletes and evaluate its reliability and validity. The reference frame was set to 1 month (4 weeks), as was done in a previous study (Sattler et al., 2021), and was decided based on the practical requirements and feasibility of using the AIS-NCA in athletes.

Moreover, to consider potential cultural or professional variations in the perception and attitudes toward sleep, this study conducted supplementary tests with a sample of Chinese students whose daily routines and time management resembled those of athletes. The aim was to preliminarily distinguish whether there are distinctive patterns in the structure linked to mainland Chinese culture or the athlete population. The daily routine management of Chinese athletes resembles that of students, with the primary distinction being that athletes prioritize sports training over academic courses as their primary daily task. Employing students as a control group enables the examination and control of factors associated with daily routine management and the influence of social jet lag, thereby circumventing the introduction of additional variations due to disparate sleep patterns and emphasizing the principal occupational characteristic of professional sports training. If the structure obtained from the athletes deviates from the original scale but aligns with that of the student sample, it may imply the impact of cultural factors. Conversely, significant disparities between the athlete and student samples would indicate the influence of the athletic profession itself.

Materials and methods

Study design

This is a descriptive, cross-sectional, and methodological study. The initial step encompassed the translation of AIS-NCA into Chinese. This translation process for AIS-NCA involved five stages: forward translation, meticulous evaluation by professionals in psychology and sports science, pilot testing and meticulous refinement of phrasing, subsequent back translation, and a series of iterative revisions guided by semantic considerations, culminating in the establishment of a consensus for the Chinese version.

Subsequent to obtaining the Chinese version of AIS-NCA, this study is prominently dedicated to exploring the structure of the Chinese rendition and validating its psychometric properties through cross-sectional surveys. In this phase, the AIS-NCA was subjected to thorough analysis and examination within two distinct cohorts: Chinese professional athletes and students whose daily routines closely paralleled those of Chinese athletes.

Participants

Four hundred twenty-six professional athletes and 779 high school students voluntarily participated in this study.

The professional athletes were recruited from Shanghai-based professional sports teams, and the students were recruited from a senior high school in Shanghai. The athletes were randomly divided into two parallel samples according to their gender and sports categories (including fencing, modern pentathlon, badminton, table tennis, shooting, archery, boxing, judo, basketball, softball, hockey, handball, Chinese martial arts, Taekwondo, and gymnastics). Sample 1 included 213 athletes (118 females and 95 males, $M_{age} = 18.93$, $SD = 3.88$) for exploratory factor analysis, while Sample 2 included 213 people (111 females and 102 males, $M_{age} = 19.05$, $SD = 3.81$) for confirmatory factor analysis. Both samples were combined to calculate internal consistency coefficients. For retest reliability, 143 athletes participated in a 1-week retest (Sample 3: 64 females and 79 males, $M_{age} = 19.62$, $SD = 3.92$), and 119 athletes participated in a 2-week retest (Sample 4: 51 females and 68 males, $M_{age} = 19.17$, $SD = 3.78$). In addition, 239 athletes completed the AIS-NCA, and the scales used to examine validity (Sample 5: 148 females and 91 males, $M_{age} = 18.87$, $SD = 3.84$).

Students were randomly divided into two parallel samples based on gender and class. These two samples were used to conduct exploratory factor analysis (Sample 6: 389 students in total, 191 females and 198 males, $M_{age} = 15.79$, $SD = 1.05$) and confirmatory factor analysis (Sample 7: 390 students in total, 177 females and 213 males, $M_{age} = 15.77$, $SD = 0.71$), respectively. These two samples were also combined for the calculation of internal consistency coefficients. 202 students participated a retests after 2-week intervals and completed the scales used to test the validity of the AIS-NCA at the time of retesting (Sample 8: 97 females and 105 males, $M_{age} = 15.33$, $SD = 0.48$).

The study received ethical approval from the Ethics Committee of the Shanghai Research Institute of Sports Science (Shanghai Anti-doping Agency; No. LLSC20220005), and adheres to the ethical principles outlined in the Declaration of Helsinki and the Standards for Ethics in Sport and Exercise Science Research (Tyebkhan, 2003; Harriss et al., 2019). Prior to the test, all participants provided written consent. Additionally, athletes and students obtained permission from their respective sports teams or schools before participating in the study.

Measures

Athens insomnia scale for non-clinical application

The Athens insomnia scale for non-clinical application (AIS-NCA) was adapted from the Athens Insomnia Scale and comprises seven items, each rated on a 5-point scale. The options for each item are represented by text that matches the content of the item. The scale comprises two dimensions, sleep problems and daytime functioning, which allow for the computation of two subscale scores and a total scale score. Higher scores indicate more severe sleep quality issues (Sattler et al., 2021).

In this study, the Chinese version of the AIS-NCA was developed through a rigorous process, which included translation and back-translation, after getting permission from the authors of AIS-NCA. Specifically, two sports science researchers and one teacher, all with professional backgrounds in psychology, independently translated the original scale into Chinese. These translations were then compiled and revised by a sports science researcher with a psychology background and a specialist with backgrounds in both English and kinesiology after a thorough discussion. The revised version was then pilot-tested multiple times with athletes of varying sports and age groups, and the text was further revised based on their feedback. The Chinese version of the scale for back-translation was then formed.

Then, the initial version was back-translated into English by a psychological specialist who obtained a psychology degree from an English-speaking country but did not take part in the initial translation. A native English-speaking professional then reviewed the items and suggested changes until there was a consensus on the semantics. The Chinese version of the scale obtained through this process was used in this study.

Pittsburgh sleep quality index

Pittsburgh sleep quality index (PSQI) is a widely used sleep scale that has gained popularity in the field of sports science. It consists of 19 self-rated and five other-rated items, with only 18 self-rated items being scored. These items assess sleep quality, sleep duration, sleep efficiency, sleep disturbance, sleep medication, and daytime dysfunction and require responses based on the previous month's state (Buysse, 2014). In this study, the scale was employed for analyzing convergent validity. To provide a more detailed characterization of sleep and following previous studies, separate scores were calculated for different aspects of sleep in addition to the total PSQI score (Bender et al., 2018a,b; Cellini et al., 2021; Driller et al., 2022). These dimensions included subjectively evaluated sleep quality, total sleep time, sleep latency, calculated sleep efficiency, total sleep disturbances score, and total daytime dysfunction score (a higher computed sleep efficiency score indicates better sleep quality). Sleep medication was not analyzed separately due to the restrictions on medication use in athletes and students. In this study, the overall internal consistency coefficients for the PSQI were Cronbach's $\alpha_{athlete} = 0.719$ and Cronbach's $\alpha_{student} = 0.689$.

Epworth sleepiness scale

Epworth sleepiness scale (ESS) is a widely used scale for assessing daytime sleepiness. It consists of eight daily situations in which respondents rate their likelihood of falling asleep on a four-point scale, with higher scores indicating higher levels of daytime sleepiness (Johns, 1991). In this study, the scale was employed for analyzing convergent validity. High school students did not complete the ESS because school administrators deemed some items inappropriate for completion by underage high school students. Athletes were asked to respond based on their status in the previous month in this study, and the internal consistency coefficient for the ESS was Cronbach's $\alpha = 0.796$.

Athlete sleep screening questionnaire

Athlete sleep screening questionnaire (ASSQ) is a scale developed for athletes to screen and guide interventions for sleep problems (Samuels et al., 2016). It consists of 16 items that are divided into three categories: Sleep Difficulty Score (SDS), which is the core of the ASSQ and consists of 5 items, with higher scores indicating more significant sleep difficulties; Modifiers that consist of three indexes: sleep breathing disorder, travel, and sleep type; and other items related to napping, caffeine, and electronic devices, respectively, that cannot be classified into SDS but can provide direct suggestions for sleep improvement strategies. In this study, only the SDS was used to represent the sleep quality of the athletes based on the original scale asking athletes to report based on their status in the most recent period. In this study, the SDS was employed for analyzing convergent validity. The internal consistency coefficient for the SDS in this study was Cronbach's $\alpha = 0.423$.

Warwick-Edinburgh mental well-being scale

The Warwick-Edinburgh Mental Well-Being Scale (WEMWBS) consists of 14 items and reflects mental well-being (Tennant et al., 2007). Participants were instructed to rate their experiences on a 5-point scale ranging from "never" to "always." This single-dimensional scale yields higher scores for higher levels of mental well-being. The Chinese version of this scale has been widely applied and has demonstrated good reliability and validity across various populations in China. Drawing from previous research (Sattler et al., 2021), this study employs this measurement of well-being to analyze the discriminant validity among athletes. Additionally, it is hypothesized that a significant negative correlation will be evident between the scores of WEMWBS and AIS-NCA (Tang et al., 2017). In this study, the internal consistency coefficient of WEMWBS among athletes was Cronbach's $\alpha = 0.951$.

General self-efficacy scale

The General Self-Efficacy Scale (GSES) consists of 10 items and reflects the level of optimistic self-beliefs. Participants rate themselves on a 4-point scale according to their subjective experiences, with higher scores indicating higher levels of self-efficacy. The Chinese version of this scale is widely used and demonstrates good reliability and validity (Zhang and Schwarzer, 1995). The assessment of students was integrated into an internal psychological evaluation within the school, where the GSES had already been included. However, due to administrative considerations and caution regarding introducing a scale related to mental health, the timely incorporation of WEMWBS into this assessment was not achieved. Research has indicated that general self-efficacy positively predicts sleep quality (Ghose et al., 2023). Thus, in this study, it can be used for analyzing the discriminant validity among students as an alternative. The same hypothesis of a significant negative correlation between the total score and individual dimensions applies. In this study, the internal consistency coefficient of GSES among students was Cronbach's $\alpha = 0.911$.

Procedure

Athletes were recruited to participate in this study by sports teams in both Sample 1 and Sample 2. The AIS-NCA was completed online by all athletes. Depending on the sports team's schedule, most athletes completed it independently in the designated testing room; for sports teams that could not schedule it, the teams themselves arranged the accomplishment of the scale. Athletes who had no significant competitions in the following month were recruited to complete AIS-NCAs twice at 1-or 2-week intervals, respectively, for Samples 3 and 4, and all retests were completed online. Athletes were recruited for Sample 5 to complete the AIS-NCA, PSQI, ESS, and ASSQ during long-term closed training sessions at the training base, and all scales were completed online.

Following approval from school administrators, the school psychologist organized the students to complete the AIS-NCA according to the class schedule. Those who were able to complete the AIS-NCA in class on the designated date in the course schedule used the paper-based scale; for those who were unable to coordinate their time, the class teacher distributed the test link, and the students completed the scale online after school on their own (Sample 6 and Sample 7). A retest was organized in those classes that were willing to participate in the retest after a 2-week interval, and students who participated completed the PSQI at the same time (Sample 8), all using the paper-based questionnaire.

Statistical analysis

Data were organized using Microsoft Excel 2016. SPSS 26.0 was used for exploratory factor analysis (EFA) and reliability and validity tests, and Amos 20.0 was used for confirmatory factor analysis (CFA). The Kaiser-Meyer-Olkin and Bartlett's spherical tests were used in the EFA to determine whether the data were suitable for factor analysis. Principal component analysis with maximum variance rotation was used to analyze the factors with an eigenvalue greater than 1. Items with factor loadings of at least 0.320 were retained (Costello and Osborne, 2005). Based on prior research, items with multiple high loadings were removed using two criteria. First, items with loadings differing by less than 0.150 across different factors were deleted (Worthington and Whittaker, 2006; Sattler et al., 2021). Second, items with strong loadings exceeding 0.500 on more than one factor were also removed (Costello and Osborne, 2005).

In the CFA, model fit was evaluated using the χ^2/df ratio, comparative fit index (CFI), adjusted goodness of fit index (AGFI), Tucker–Lewis index (TLI), and root mean square error of approximation (RMSEA). Previous studies were consulted to establish the acceptable criteria: a χ^2/df ratio below 5.00 (preferably below 2), CFI, AGFI, and TLI values greater than 0.90, and RMSEA values below 0.08 (Nock et al., 2009; Sattler et al., 2021). Furthermore, multiple-group analysis (multiple-group CFA) was conducted to examine the measurement invariance across different genders of athletes and students. Additionally, comparisons were also carried out between athlete and student samples. Various models within the multiple-group CFA were systematically compared, including the Unconstrained Model, Measurement Weights Model, Structural Covariances Model, and Measurement Residuals Model.

The intraclass correlation coefficient (ICC) was utilized to examine test–retest reliability. Convergent and discriminant validity were evaluated using Pearson correlation coefficients. Internal consistency reliability was assessed using both Cronbach's α coefficient and McDonald's ω coefficient.

Results

Athletes

EFA

An exploratory factor analysis was conducted on the Chinese version of the AIS-NCA using Sample 1. The results of Kaiser Meyer Olkin test and Bartlett's test of sphericity showed that the sample was sufficient for factor analysis [KMO = 0.783; $\chi^2(21) = 467.817$, $p < 0.001$]. The results revealed two factors with eigenvalues greater than 1 (Factor 1 = 3.187, Factor 2 = 1.274), which accounted for 63.73% of the variance (Factor 1 = 33.35%, Factor 2 = 30.38%). Item 4 ("The overall quality of my sleep was usually…") had high and similar loadings on both factors and met the criteria for exclusion.

After the removal of item 4, the factor analysis was rerun, and revealed that KMO = 0.707, and the result of Bartlett's spherical test also indicated suitability for factor analysis [$\chi^2(15) = 330.222$, $p < 0.001$]. The analysis revealed two factors with eigenvalues greater than 1 (Factor 1 = 2.644, Factor 2 = 1.274), accounting for 65.08% of the variance (Factor 1 = 35.53%, Factor 2 = 29.55%). The remaining six items on the two factors were consistent with the original scale (Table 1), and the two factors were named Sleep Problems and Daytime Functioning, based on the nomenclature of the original scale. Subsequent analyses were conducted with the 6-item AIS-NCA among athletes.

CFA

CFA was initially conducted on a one-factor model using six items, leading to $\chi^2/df = 9.490$, CFI = 0.803, AGFI = 0.725, TLI = 0.671, and RMSEA = 0.200, indicating a poor fit. Subsequently, a CFA was carried out on a two-factor structure derived from exploratory factor analysis, leading to $\chi^2/df = 2.217$, CFI = 0.975, AGFI = 0.929, TLI = 0.953, and RMSEA = 0.076, demonstrating a good model fit (refer to Figure 1A for each path loading).

TABLE 1 Factor loadings of the AIS-NCA among athletes.

	7 items		6 items	
	Sleep problems	Daytime functioning	Sleep problems	Daytime functioning
Item 1	**0.580**	0.350	**0.541**	0.361
Item 2	**0.843**	0.075	**0.862**	0.104
Item 3	**0.779**	0.020	**0.815**	0.050
Item 4	**0.624**	**0.512**	-	-
Item 5	0.260	**0.814**	0.238	**0.822**
Item 6	0.099	**0.842**	0.101	**0.855**
Item 7	0.072	**0.756**	0.078	**0.763**

The bold numbers in the table indicate that the item can be attributed to that dimension.

Invariance analysis

Expanding on the foundation of the CFA, an additional analysis was undertaken using Sample 2 to explore the measurement invariance of the AIS-NCA across athletes of different genders through a multi-group analysis. The constrained measurement weights model, where loadings were constrained to be equal, was compared to the Unconstrained Model. The results showed a negligible difference with $\Delta\chi^2 = 1.732$, $\Delta df = 4$, and $p = 0.785$. Additionally, the changes in fit indices were minimal, with ΔCFI = 0.006, ΔAGFI = 0.017, ΔTLI = 0.022, and ΔRMSEA = −0.012 when compared to the Unconstrained Model. Furthermore, a structural covariances model was contrasted with the Measurement Weights Model. The comparison indicated a difference with $\Delta\chi^2 = 14.297$, $\Delta df = 3$, and $p = 0.003$. The differences in fit indices were observed, including ΔCFI = −0.032, ΔAGFI = −0.024, ΔTLI = −0.037, and ΔRMSEA = 0.018 when compared to the Measurement Weights Model. Lastly, a measurement residuals model was compared to the Structural Covariances Model. The results revealed no statistically significant difference with $\Delta\chi^2 = 6.783$, $\Delta df = 6$, and $p = 0.341$. The changes in fit indices were negligible, with ΔCFI = −0.002, ΔAGFI = 0.009, ΔTLI = 0.014, and ΔRMSEA = −0.006 when compared to the Structural Covariances Model.

Reliability

The one-week retest intraclass correlation coefficients (ICC) were significant and indicative of good reliability for the total score (ICC = 0.737, $p < 0.001$), the sleep problems dimension (ICC = 0.745, $p < 0.001$), and the daytime functioning dimension (ICC = 0.599, $p < 0.001$). The two-week retest ICC was also significant but slightly lower for the total score (ICC = 0.517, $p < 0.001$), the sleep problems dimension (ICC = 0.525, $p < 0.001$), and the daytime functioning dimension (ICC = 0.451, $p < 0.001$).

The internal consistency coefficients were also good, with Cronbach's α = 0.729 and McDonald's ω = 0.708 for the six AIS-NCA items, Cronbach's α = 0.666 and McDonald's ω = 0.721 for the sleep problems, and Cronbach's α = 0.773 and McDonald's ω = 0.784 for the daytime functioning.

Convergent and discriminant validity

With the exception of the non-significant correlation coefficient between the AIS-NCA sleep problem scores and PSQI-sleep duration, there were significant correlations observed between the total AIS-NCA scores and the scores of both dimensions with the total PSQI scores and scores of subscales, as well as with ESS and ASSQ-SDS, indicating strong convergent validity. Moreover, moderate negative correlations were observed between AIS-NCA total scores, its dimension scores, and WEMWBS, demonstrating good discriminant validity (refer to Table 2 for correlation coefficients).

Students

EFA

An exploratory factor analysis was conducted on the Chinese version of the AIS-NCA using Sample 6. The results of Kaiser Meyer Olkin test and Bartlett's test of sphericity showed that the sample was sufficient for factor analysis [KMO = 0.799; $\chi^2(21) = 1045.499$, $p < 0.001$]. The results revealed two factors with

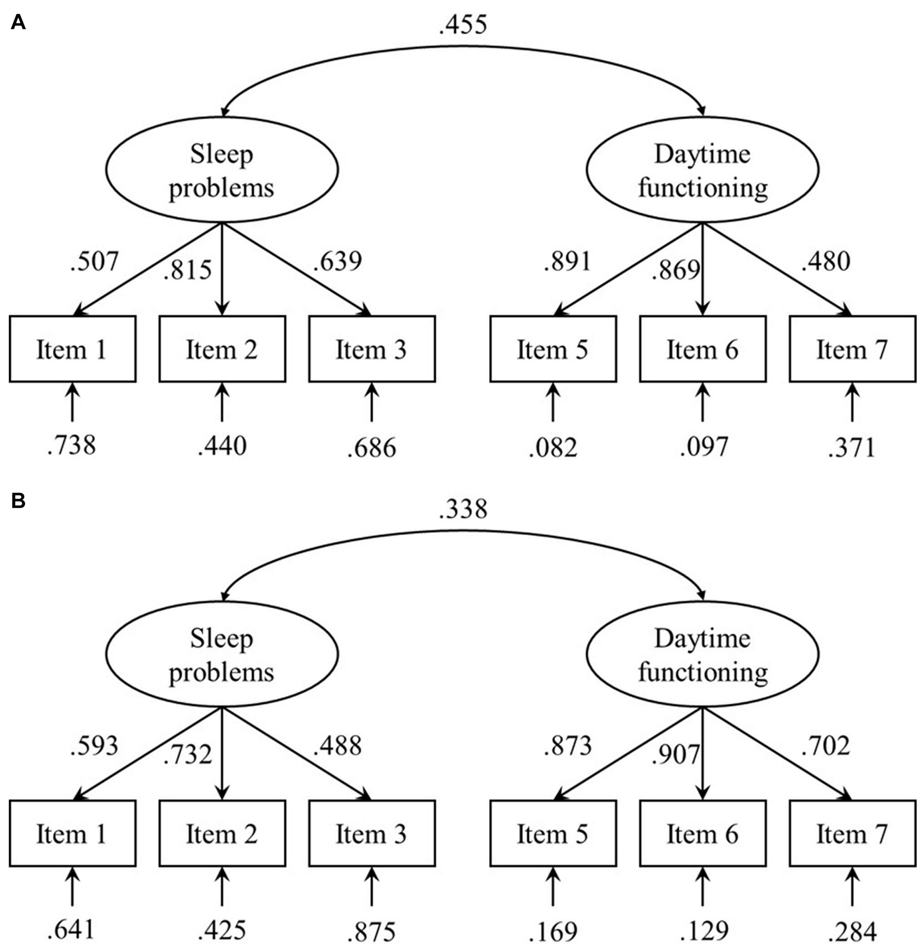

FIGURE 1
CFA parameter estimates for athletes **(A)** and students **(B)**.

eigenvalues greater than 1 (Factor 1 = 3.359, Factor 2 = 1.204), which accounted for 65.18% of the variance (Factor 1 = 37.74%, Factor 2 = 27.44%). Similar to the athlete sample, item 4 had high and similar loadings on both factors and met the criteria for exclusion.

After the removal of item 4, the factor analysis was rerun and revealed that KMO = 0.743, and the result of Bartlett's spherical test also indicated suitability for factor analysis [$\chi^2(15) = 773.024$, $p < 0.001$]. The analysis revealed two factors with eigenvalues greater than 1 (Factor 1 = 2.810, Factor 2 = 1.163), accounting for 66.22% of the variance (Factor 1 = 40.30%, Factor 2 = 25.92%). The remaining six items on the two factors were consistent with the original scale (Table 3), and the two factors were named Sleep Problems and Daytime Functioning, based on the nomenclature of the original scale. Subsequent analyses were conducted with the 6-item AIS-NCA among students.

CFA

CFA was initially conducted on a one-factor model using six items, leading to $\chi^2/df = 15.062$, CFI = 0.840, AGFI = 0.747, TLI = 0.733, and RMSEA = 0.190, indicating a poor fit. Subsequently, a CFA was carried out on a two-factor structure derived from exploratory factor analysis, leading to $\chi^2/df = 3.037$, CFI = 0.979, AGFI = 0.947, TLI = 0.961, and RMSEA = 0.072, demonstrating a good model fit (refer to Figure 1B for each path loading).

Invariance analysis

An analysis of measurement invariance among students of different genders was conducted using Sample 7. The constrained measurement weights model was compared to the Unconstrained Model. The results showed a slight difference with $\Delta\chi^2 = 10.388$, $\Delta df = 4$, $p = 0.034$. Moreover, there were negligible changes in the fit indices, including ΔCFI = −0.009, ΔAGFI = 0, ΔTLI = −0.002, and ΔRMSEA = 0.002, in comparison to the Unconstrained Model. Additionally, the structural covariances model was contrasted with the Measurement Weights Model. The comparison did not find a difference with $\Delta\chi^2 = 3.351$, $\Delta df = 3$, $p = 0.341$. The variations in fit indices were minimal, with ΔCFI = 0, ΔAGFI = 0.005, ΔTLI = 0.006, and ΔRMSEA = −0.004, compared to the Measurement Weights Model. Moreover, the measurement residuals model was compared to the Structural Covariances Model. The results showed no difference with $\Delta\chi^2 = 6.082$, $\Delta df = 6$, $p = 0.414$. The changes in fit indices were also negligible, with ΔCFI = 0, ΔAGFI = 0.008, ΔTLI = 0.009, and ΔRMSEA = −0.006, in comparison to the Structural Covariances Model.

TABLE 2 Correlation coefficients between AIS-NCA, PSQI, ESS, ASSQ, and WEMWBS (Athletes).

	n	AIS-NCA Total Score	AIS-NCA Sleep problems	AIS-NCA Daytime functioning
PSQI	232	0.637 ($p < 0.001$)	0.529 ($p < 0.001$)	0.596 ($p < 0.001$)
- Subjective sleep quality	232	0.620 ($p < 0.001$)	0.554 ($p < 0.001$)	0.527 ($p < 0.001$)
- Sleep latency	232	0.530 ($p < 0.001$)	0.495 ($p < 0.001$)	0.422 ($p < 0.001$)
- Sleep duration	232	0.149 ($p = 0.023$)	0.079 ($p = 0.228$)	0.199 ($p = 0.002$)
- Sleep efficiency	232	−0.313 ($p < 0.001$)	−0.204 ($p = 0.002$)	−0.365 ($p < 0.001$)
- Sleep disturbance	232	0.554 ($p < 0.001$)	0.536 ($p < 0.001$)	0.417 ($p < 0.001$)
- Daytime functioning	232	0.533 ($p < 0.001$)	0.345 ($p < 0.001$)	0.628 ($p < 0.001$)
ESS	239	0.637 ($p < 0.001$)	0.529 ($p = 0.001$)	0.596 ($p < 0.001$)
ASSQ-SDS	239	0.299 ($p < 0.001$)	0.213 ($p < 0.001$)	0.329 ($p < 0.001$)
WEMWBS	239	−0.424 ($p < 0.001$)	−0.440 ($p < 0.001$)	−0.442 ($p < 0.001$)

TABLE 3 Factor loadings of the AIS-NCA among students.

	7 items		6 items	
	Sleep problems	Daytime functioning	Sleep problems	Daytime functioning
Item 1	**0.617**	0.308	**0.575**	0.331
Item 2	**0.759**	0.183	**0.757**	0.208
Item 3	**0.697**	−0.064	**0.765**	−0.044
Item 4	**0.639**	**0.527**	-	-
Item 5	0.172	**0.872**	0.158	**0.879**
Item 6	0.157	**0.899**	0.157	**0.906**
Item 7	0.127	**0.815**	0.130	**0.819**

The bold numbers in the table indicate that the item can be attributed to that dimension.

Furthermore, an invariance analysis was conducted between athletes and students using Samples 2 and 7. The constrained measurement weights model, compared to the Unconstrained Model, yielded $\Delta\chi^2 = 5.773$, $\Delta df = 4$, $p = 0.217$. Additionally, the changes in fit indices were minor, with $\Delta CFI = -0.002$, $\Delta AGFI = 0.004$, $\Delta TLI = 0.007$, and $\Delta RMSEA = -0.004$, when compared to the Unconstrained Model. Likewise, the structural covariances model was compared with the Measurement Weights Model. The comparison revealed a significant difference with $\Delta\chi^2 = 31.397$, $\Delta df = 3$, and $p < 0.001$. The differences in fit indices were minor, including $\Delta CFI = -0.024$, $\Delta AGFI = -0.019$, $\Delta TLI = -0.027$, and $\Delta RMSEA = 0.016$, when compared to the Measurement Weights Model. Lastly, the measurement residuals model was contrasted with the Structural Covariances Model. The results demonstrated a statistically significant difference with $\Delta\chi^2 = 29.176$, $\Delta df = 6$, and $p < 0.001$. The changes in fit indices were minor, with $\Delta CFI = -0.020$, $\Delta AGFI = -0.004$, $\Delta TLI = -0.008$, and $\Delta RMSEA = 0.003$, compared to the Structural Covariances Model.

Reliability

The two-week retest ICC was also significant but slightly lower for the total score (ICC = 0.649, $p < 0.001$), the sleep problems dimension (ICC = 0.639, $p < 0.001$), and the daytime functioning dimension (ICC = 0.576, $p < 0.001$).

The internal consistency coefficients were also good, with Cronbach's $\alpha = 0.729$ and McDonald's $\omega = 0.701$ for the six AIS-NCA items, Cronbach's $\alpha = 0.575$ and McDonald's $\omega = 0.593$ for the sleep problems, and Cronbach's $\alpha = 0.865$ and McDonald's $\omega = 0.875$ for the daytime functioning.

Convergent and discriminant validity

Significant correlations were observed between the total AIS-NCA scores and the scores of both dimensions with the total PSQI scores and subscales scores, indicating strong convergent validity. Moreover, moderate negative correlations were observed between AIS-NCA total scores, its dimension scores, and GSES, demonstrating good discriminant validity (refer to Table 4 for correlation coefficients).

Discussion

Athletes' sleep is essential for more than simply health reasons; it also helps them perform better in competition (Dorrian and Dinges, 2006; Malhotra, 2017; Bonnar et al., 2018; O'Donnell et al., 2018; Walsh et al., 2021). Accurate and reliable quantitative assessments of their sleep are required to boost athletes' health and performance by describing, detecting, and improving their sleep.

Scales have long been a popular measure for monitoring sleep quality. In practice, classical sleep quality assessment scales and screening tools have contributed significantly to research on sleep quality risk assessment and enhancement in athletes (Mah et al., 2018;

TABLE 4 Correlation coefficients between AIS-NCA, PSQI, and GSES (Students).

	n	AIS-NCA total score	AIS-NCA sleep problems	AIS-NCA daytime functioning
PSQI	188	0.772 ($p < 0.001$)	0.612 ($p < 0.001$)	0.611 ($p < 0.001$)
- Subjective sleep quality	188	0.692 ($p < 0.001$)	0.616 ($p < 0.001$)	0.476 ($p < 0.001$)
- Sleep latency	188	0.563 ($p < 0.001$)	0.651 ($p < 0.001$)	0.233 ($p = 0.001$)
- Sleep duration	188	0.296 ($p < 0.001$)	0.144 ($p = 0.049$)	0.329 ($p < 0.001$)
- Sleep efficiency	188	−0.326 ($p < 0.001$)	−0.258 ($p < 0.001$)	−0.257 ($p < 0.001$)
- Sleep disturbance	188	0.591 ($p < 0.001$)	0.573 ($p < 0.001$)	0.359 ($p < 0.001$)
- Daytime functioning	188	0.525 ($p < 0.001$)	0.146 ($p = 0.046$)	0.695 ($p < 0.001$)
GSES	195	−0.389 ($p < 0.001$)	−0.165 ($p = 0.021$)	−0.457 ($p < 0.001$)

Bender et al., 2018a,b; Halson, 2019; Rebello et al., 2022; Suppiah et al., 2022), facilitating the development and application of sleep science in sports. Yet, researchers have grown increasingly conscious that the scales used to assess sleep quality in athletes were designed largely for clinical use, despite the fact that the vast majority of populations tested did not include patients with clinical issues. Consequently, using scales intended for clinical purposes may lead to potential deficiencies or problems in the outcomes and practice of the study (Sattler et al., 2021).

To address concerns about potential scale challenges, researchers created the AIS-NCA and demonstrated its validity and applicability in the general population (Sattler et al., 2021). This study aimed to revise and validate the AIS-NCA scale among Chinese athletes and further investigate the potential influence of cultural differences or professional characteristics in a non-athlete population. This research provided an initial exploration of the applicability of AIS-NCA among Chinese athletes. The findings demonstrated that AIS-NCA can be effectively utilized within the Chinese athlete population. However, the revised scale exhibited both similarities and notable differences compared to the original version. Regarding the scale's dimensions and items, the Chinese version of the AIS-NCA covers the same two categories as the original scale: sleep problems and daytime functioning. This study also showed that the structure is not exclusive to athletes. Although the authors of the AIS did not explicitly propose this two-factor structure, they did suggest, at an operational level, that the items belonging to the first dimension be used separately as short scales (Soldatos et al., 2000). This suggestion indirectly supports the two-factor structure. Perhaps because the AIS was developed based on the ICD-10, clinical use as a diagnostic aid is prioritized over differentiating the dimensions of sleep quality (Soldatos et al., 2000; Hallit et al., 2019). Nonetheless, for non-clinical purposes, the division into two dimensions allows for a more comprehensive analysis and investigation of the links between aspects of sleep quality (Sattler et al., 2021). It might also present new approaches to investigating the relationship between sleep and sports performance.

The Chinese version of AIS-NCA demonstrates consistency with the original questionnaire in terms of dimensions, but a notable difference appears in one specific item. Whether among athletes or non-athletes, the items related to subjective sleep quality or satisfaction with sleep quality exhibit strong and similar loadings on both dimensions. It can be inferred that Chinese athletes' cognition of subjective sleep quality may differ from that of the groups involved in previous studies, which may be the main reason for this phenomenon.

Some researchers have emphasized that sleep quality can be defined as an individual's self-satisfaction with various aspects of their sleep experience and is a concept with ambiguous boundaries (Harvey et al., 2008; Nelson et al., 2022). Studies using interviews and other methods have revealed that when discussing sleep quality, both insomnia patients and the general population include not only sleep-related issues such as nighttime awakenings but also experiences associated with daytime functioning, such as fatigue and recovery (Harvey et al., 2008). Additionally, other researchers have suggested that differences in how individuals define ideal sleep can influence their subjective perceptions (Buysse, 2014), indicating that subjective sleep quality may be linked to the content of sleep quality definitions.

Considering that this phenomenon was observed among athletes and non-athletes in this study, it is conceivable that this perception of sleep quality may stem from cultural factors. For instance, researchers found that objective sleep quality in Japanese university students was lower than that of European-Canadian students, but they did not report matching levels of fatigue and health. However, Asian-Canadians living in a Canadian cultural context showed patterns similar to European-Canadians (Cheung et al., 2021). While cross-cultural research on this topic is somewhat limited, existing studies suggest that cultural norms surrounding sleep indeed exist and may influence subjective experiences, potentially relating to the content of sleep quality.

Since cultural factors may account for the differences in AIS-NCA items, one might wonder whether these differences could also be associated with the athlete population. Examining the structural disparities of AIS-NCA between athletes and non-athletes, it becomes evident that both groups exhibit consistent patterns, not only regarding the phenomenon related to subjective sleep quality items but also in the loadings of all the items. These disparities are only evident when introducing covariance and residuals into the model. Based on this finding, it is reasonable to infer that AIS-NCA demonstrates a comparable structure among athletes and non-athletes, with item differences more likely stemming from cultural influences rather than occupational factors.

Regarding the measurement invariance of the AIS-NCA, this study revealed a high level of consistency in structure and loadings among athletes of different genders and between athlete and student samples. However, some limitations emerged when incorporating controlled covariances and residual models. In the initial research introducing the AIS-NCA, scholars demonstrated good scalar invariance across gender, age groups, sleep disorders, and cross-linguistic samples in a large-scale study (Sattler et al., 2021). In this study, different gender samples exhibited satisfactory equivalence at the structural and loading levels, yet slightly weaker equivalence after introducing residuals, compared to previous research. A similar phenomenon was observed in the model comparison between athletes and the general population. This could be related to the exclusion of the subjective sleep quality item in this study and potential underlying cultural differences to some extent. This outcome might suggest that when applying the AIS-NCA to Chinese athletes and the general population, more attention to the issue of invariance is required, especially compared to its application in English-or German-speaking contexts. Nevertheless, research in this area remains limited, highlighting the need for further analysis and interpretation of cross-population measurement invariance in a broader array of populations.

Regarding the validity of the AIS-NCA, both for athletes and the non-athlete population, significant positive correlations were found between PSQI, ESS, ASSQ, and AIS-NCA scores, indicating strong Convergent Validity. AIS-NCA's Discriminant Validity also demonstrated the expected patterns among athletes and the general population. Overall, the revised AIS-NCA exhibited robust validity. Additionally, it is noteworthy that the analysis of Convergent Validity involved several indicators. These findings not only support the validity of the AIS-NCA but also shed light on its unique characteristics regarding the assessment of various sleep features. Such insights contribute positively to understanding the features of the AIS-NCA tool and its application recommendations.

Concerning the relationship between AIS-NCA and PSQI, specifically focusing on the sleep disorders and daytime functioning dimensions of PSQI, noticeable differences in correlation coefficients of the two dimensions of AIS-NCA were observed. This outcome further underscores the relatively strong validity of AIS-NCA's two dimensions. However, the correlation coefficients were relatively low for AIS-NCA total scores or the scores of its two dimensions with sleep duration and sleep efficiency in PSQI. This result indicates that AIS-NCA itself may not fully describe the intricacies of sleep characteristics and should be complemented by consensus sleep diaries or other objective methods (Carney et al., 2012).

In contrast to the findings for the daytime functioning dimension in the PSQI, the AIS-NCA scores displayed moderate correlations with the score for both dimensions on the Epworth Sleepiness Scale (ESS). However, the differences in correlation coefficients between the sleep disturbance and daytime functioning dimensions were not as pronounced as those observed on the PSQI. This phenomenon is consistent with the results obtained in the original questionnaire (Sattler et al., 2021). Two possible explanations for these findings are proposed. Firstly, the ESS primarily reflects sleepiness rather than overall daytime functioning (Johns, 1991). While sleepiness requires recuperation through sleep (Mairesse et al., 2017), it does not necessarily represent daytime functioning in its entirety. Secondly, some ESS items may be unfamiliar or difficult to imagine for Chinese athletes, such as "watching TV" and "reading, "which may not be everyday activities in their daily lives. As a result, the validity of the ESS may be reduced due to reliance on imagination.

The correlation coefficients obtained on the SDS were low. This result may be attributable to the ASSQ's intended use, which includes assessing athletes for sleep issues and making hierarchical intervention recommendations (Samuels et al., 2016). The SDS employs a multiple-choice format, and the ability to provide a precise evaluation of overall or specific aspects of sleep quality in athletes is not deemed critical. Looking at this more constructively, augmenting the use of the ASSQ with the AIS-NCA in athletes may have added advantages. Specifically, incorporating AIS-NCA in the periodic assessment of athletes without sleep disorders could enhance training and recovery quality, while tracking athletes with sleep disorders could facilitate the evaluation of intervention efficacy and progress.

Regarding reliability, the overall internal consistency coefficient is satisfactory, and the results obtained from athletes are similar to those of the original study. However, it was observed that non-athlete students' consistency coefficient for sleep problems is not high enough. It is essential to highlight that even among athletes, the consistency coefficient for this dimension is also relatively low. This observation is reflected in the loadings of the factors. This discrepancy may be attributed to the complex relationship between sleep indicators, as even the PSQI questionnaire lacks conclusive evidence regarding the number and content of dimensions (Raniti et al., 2018; Jia et al., 2019; Guo, 2022). Therefore, further investigation of the relationship between different sleep indicators may be warranted, possibly incorporating additional moderator variables.

The retest reliability of the AIC-NCA was evaluated over 1-week and 2-week intervals among athletes and non-athletes, respectively. The reliability of the 1-week retest was good and only slightly lower than that reported in previous studies (Sattler et al., 2021). Although still satisfactory, the 2-week retest reliability was lower than the 1-week retest. This disparity may be attributed to factors such as training and fatigue, which can affect athletes' sleep quality (Lastella et al., 2018, 2020). This could also be true for students who represented the general population and were subject to factors such as on-campus activities and exams, which could alter their sleep status during retest. It is suggested that the sleep quality obtained from AIC-NCA may reflect a more recent period. Thus, it requires consideration of recent training and recovery to avoid misinterpretation when athletes are asked to report on a more extended period. However, it also suggests that AIC-NCA may be more sensitive to changes in sleep quality and suitable for the evaluation and timely intervention of athletes' sleep quality over shorter or specific periods, such as different phases of the season (Biggins et al., 2021; Saidi et al., 2022).

Overall, this study proves that the Chinese version of AIS-NCA is effective for assessing sleep among Chinese athletes, demonstrating good reliability and validity within a short timeframe (1 month). It comprehensively evaluates athletes' sleep by considering sleep problems and daytime functioning. When using AIS-NCA with Chinese athletes, the 6-item version is recommended. However, considering potential cultural factors and facilitating cross-cultural research or subjective sleep quality analyses, completion of the 7-item version is suggested while excluding the excluded item from calculations. Moreover, the Chinese version of AIS-NCA also exhibits promising applicability among high school students outside the athlete population, which carries positive implications for cross-population comparisons, especially in student-athlete research. Nevertheless, caution is advised when applying it to high school students based on the validity obtained in this study.

The Chinese version of AIS-NCA complements existing methods for assessing athlete sleep quality, providing valuable support for research and applications related to sports training, fatigue recovery, and athlete mental health. However, this study has several limitations. Firstly, it represents a preliminary revision of the Chinese version of AIS-NCA, lacking sensitivity testing concerning athletes' training and competitions, and assessments across different time frames, which leaves the full potential of its application value and characteristics in sports training unexplored. Secondly, the criterion measures used were self-report scales, making the response subjective, and objective measures were not employed due to practical constraints. Thirdly, the non-athlete group was confined to high school students with similar time management in their daily routines, restricting the explanatory power regarding cultural and occupational influences and the generalizability of use in a broader population.

Future research can further integrate daily training and actual competitions to examine the reliability of AIS-NCA in assessing sleep quality during these activities within shorter timeframes, and explore ways to incorporate it into training programs. Additionally, more profound explorations of the significance of the two dimensions should be conducted by combining objective sleep indicators. Moreover, it is imperative to consider cultural differences and the impact of occupation and population characteristics to delve into the distinctive features of Chinese cultural cognition regarding sleep quality. Furthermore, the effectiveness and invariance of AIS-NCA should be further tested in a broader population, with particular attention to the role of population characteristics. This will expand the scale's applicability in Chinese people and provide insights into analyzing sleep characteristics among Chinese athletes.

Conclusion

The Chinese version of the Athens Insomnia Scale for Non-clinical Application retains the exact two dimensions as the original scale: sleep problems and daytime functioning, while excluding one item related to subjective sleep quality. The Chinese version of the scale demonstrates good reliability and validity, making it suitable for assessing sleep quality among Chinese athletes. The structure among Chinese athletes may reflect specific cultural differences. While it shows promise for application in other Chinese populations, a caution approach is recommended.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the Ethics Committee of Shanghai Research Institute of Sports Science (Shanghai Anti-doping Agency). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants. For minors, written informed consent was provided by their legal guardians or next of kin.

Author contributions

CT and JQ conceptualized the study. CT, JW, GC, CC, JY, and JL organized the data collection. CT wrote the first draft of the manuscript. CT and JW run the analyses and wrote the results section. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The role of motivation and emotions in physical education: understanding academic achievement and the intention to be physically active

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Introduction: This study aims to understand how emotions and motivation influence the academic achievement of physical education (PE) students and their future intention to practice physical activity (PA). Despite the influence on student's behaviors and the reciprocal associations between motivation and emotion, the number of studies addressing both constructs at the same level is very limited.

Methods: A structural equation model was used with 799 students aged 11–17 years (M = 13.16; SD = 1.17).

Results and discussion: The results showed that the teacher support of the basic psychological needs (BPN) predicted students' BPN satisfaction, which in turn predicted their autonomous motivation and positive emotions, and negatively predicted their negative emotions. Finally, autonomous motivation predicted students' intention to be physically active, whereas academic achievement was predicted by both autonomous motivation and emotions. We conclude that to better understand the consequences of PE classes, it is necessary to consider both constructs.

KEYWORDS

self-determination theory, control-value theory, physical activity, achievement emotions, academic performance

1. Introduction

Motivation and emotions are seen as prerequisites, mediators and even consequences of both learning and academic achievement, helping us to understand people's behavior (Reeve, 2010; Pekrun et al., 2017). Both constructs, motivation and emotion, although they bear some similarity, are different (Løvoll et al., 2017). Motivation refers to the processes that give energy and direction to human behavior (Reeve, 2010), whereas, emotions are interrelated psychological processes consisting of cognitive, physiological, affective, expressive and motivational processes (Scherer, 2009). Emotions can influence people's behaviors in various ways (Meyer and Turner, 2006). On the one hand, we find that the emotions experienced after an event help to maintain the pre-established motivation (Løvoll et al., 2017), indicating whether the situation is okay or it needs to change (Reeve, 2010). On the other hand, emotions can cause new directions in changing behavior (Løvoll et al., 2017), that is, they can function as a type of motive in themselves (Reeve, 2010). These internal processes (motivation and emotion) occur separately, because people differ in both emotional perception and in their motivational response to that perception (Roth et al., 2019). Although it does not occur in all cases, emotional behavior is usually associated with more impulsive behaviors while motivational behavior could be considered more deliberate (Roseman, 2013).

Theories that link emotion, cognition, and motivation have traditionally arranged the relationships between them hierarchically or chronologically (Meyer and Turner, 2006), that is, they have alternated between emphasizing motives versus emotions as sources of energy and control of behavior (Roseman, 2013). For instance, some authors (e.g., Izard, 1991; Lazarus, 1991) established the priority of emotions over cognitive or motivational aspects, a trend that has been studied over the years (Vandercammen et al., 2014). On the other hand, other authors have established the prioritization of motivation over emotion in the understanding of human behavior, relegating the emotional role to the consequences and not to the causes of behavior (Deci and Ryan, 1985; Ford, 1992). In the last decade, the interrelation between cognition, emotion and motivation has been demonstrated (Reeve, 2010). Specifically, in the educational field (Ramirez-Arellano et al., 2019; Järvenoja et al., 2020), this interrelation occurs within a complex system of co-regulation between students and teachers (Meyer and Turner, 2006). Thus, observation of teacher instructions associated with intrinsic or autonomous motivation (i.e., doing something because it is interesting or enjoyable) revealed the impossibility of differentiating between motivational and emotional aspects (e.g., smiling or joking on the part of the teacher when giving corrections) (Meyer and Turner, 2006), however, it is possible to differentiate in terms of individual perception (e.g., Ramirez-Arellano et al., 2019; Van Roekel et al., 2019). Therefore, the various emotional regulation processes exert an influence on volitional functioning, personal well-being and high-quality relationships (Roth et al., 2019), aspects that are closely related to those needs associated with motivational behaviors (Reeve, 2010). As a result, there is reciprocal associations between the two constructs (Van Roekel et al., 2019).

To better understand students' behaviors (e.g., participation, academic achievement, disruptive problems, etc.), it is necessary to address both the emotional and motivational roles, given the interconnection between the two constructs (Roseman, 2013). Research on this topic has been requested by several authors (e.g., Meyer and Turner, 2006). Some studies have started to emerge in different educational contexts (e.g., Shao et al., 2020) however, most studies in the field of Physical Education (PE) that address student behaviors (e.g., Ulstad et al., 2016; Franco and Coterón, 2017; Cheon et al., 2018) have focused mainly on motivation, without taking into account the emotional component.

1.1. Self-determination theory

As for motivation, Self-Determination Theory (SDT; Deci and Ryan, 1985; Ryan and Deci, 2017) has been postulated as one of the main theories to understand human behavior based on an illustrative sequential model (Vasconcellos et al., 2020; Figure 1). This theory suggests that people need to feel competent (to interact effectively with the environment), autonomous (to feel that they choose to perform the behavior) and related to others (to feel connected and respected by others), and that satisfaction of these three Basic Psychological Needs (BPN) is essential for the development of motivation, well-being and performance (Ryan and Deci, 2017).

The social environment plays an important role in the satisfaction or thwarting of these BPN. Specifically, in the school environment, in which young people necessarily spend a large part of their time, teachers (as authority figures), through their interpersonal style (autonomy supportive vs. controlling), satisfy or thwart those BPN (Haerens et al., 2015; Ryan and Deci, 2017). When the teacher uses a need supporting interpersonal style with the students, offering freedom in the choice of activities and encouraging students' involvement in the decision-making process, the BPN will be satisfied, facilitating students to become more intrinsically and self-determinedly involved in their tasks (Haerens et al., 2015) and promoting performance and well-being. Whereas, if the teacher presents a controlling interpersonal style, behaving in a coercive, authoritarian way and exerting pressure on the students, these BPN will be thwarted, leading to lower motivation (Haerens et al., 2015), lower performance and greater discomfort, that is, more maladaptive consequences (Ryan and Deci, 2017).

SDT has been widely used in PE, showing to be effective in the application of intervention programs to increase students' autonomous motivation (Kelso et al., 2020). It has also been shown to be useful for investigating different consequences associated with this motivation (Cheon et al., 2018, 2020), as well as the intention to be active in the future (Cheon et al., 2012; Franco and Coterón, 2017; Castillo et al., 2020), the levels of physical activity (PA) practiced in leisure time (Castillo et al., 2020), academic achievement in PE (Cheon et al., 2012; Ulstad et al., 2016) or some emotions like enjoyment (Franco and Coterón, 2017). Therefore, SDT has taken emotions as consequences of behaviors.

1.2. Control value theory of achievement emotions

The evidence on emotions in PE is limited (Simonton and Garn, 2018) with most of the studies published on this topic being very recent. Among them, there is a clear tendency to use Control Value Theory of Achievement Emotions (CVTAE) (Pekrun, 2006) as the main theory to approach the study of emotions in the context of PE (e.g., Simonton and Garn, 2018, 2020; Fierro-Suero et al., 2020a, 2023; Zimmermann et al., 2021). CVTAE, which analyzes emotions from a cognitive-social perspective (Figure 2), maintains that achievement emotions are critical antecedents of control appraisals (competence beliefs, self-efficacy expectations, attributions of achievement) and value appraisals (perceived value of activities or outcomes) (Pekrun and Stephens, 2010). Therefore, it is suggested that control-value appraisals play a mediating role between learning environments and emotions experienced (Pekrun, 2006).

In this way, achievement emotions, as a cause to explain the behavior of students (Simonton and Garn, 2020), can be classified based on three main criteria: their valence (positive or negative), their level of activation (activating or deactivating) and the focus of the objective, that is whether it is an activity (e.g., participating in a task) or a result (e.g., winning or losing a competition) (Fierro-Suero et al., 2020a). So, emotions are specific reaction to specific tasks or situations, and not general feelings. For example, enjoyment is a positive and activating emotion focused on the activity performed. However, boredom could be considered an opposite emotion, since it is an emotion with negative valence and is deactivating also focused

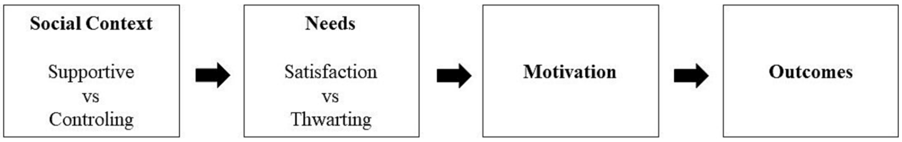

FIGURE 1
Illustrative model of self-determination theory.

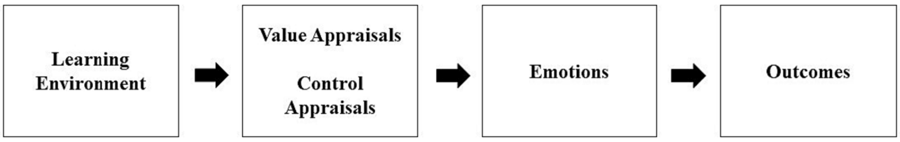

FIGURE 2
Illustrative model of control value theory of achievement emotions.

on the activity (for more information, see Fierro-Suero et al., 2023). Studies based on CVTAE principles have shown the importance of the emotions experienced during PE classes in explaining outcomes such as academic achievement, commitment, disruptive behaviors, PA levels or future intention to practice (Simonton and Garn, 2020; Zimmermann et al., 2021; Fierro-Suero et al., 2023).

1.3. Relation between SDT and emotions

Motivation and emotions separately have been shown to be consistent and effective in explaining behaviors such as PA level, future intention to practice, academic achievement or disruptive behavior in PE classes (Ulstad et al., 2016; Franco and Coterón, 2017; Simonton and Garn, 2020; Zimmermann et al., 2021; Fierro-Suero et al., 2023). However, few investigations so far have addressed the study of both constructs simultaneously in PE (Fierro-Suero et al., 2022, 2023). Given the similarity between the postulates of CVTAE and SDT, this study proposes to incorporate the emotional and motivational roles into understanding the consequences of PE classes.

It is known that emotions are omnipresent in classrooms and essential to understanding educational interactions (Meyer and Turner, 2006). In the educational environment, students will experience a type of emotion that depends on whether or not their expectations are met (Meyer and Turner, 2006). The fulfillment of expectations is mediated by conscious or unconscious evaluations of what happens to us (Pekrun and Stephens, 2010). These regulatory processes are associated with the level of satisfaction of the BPN (Ryan and Deci, 2001). That is, emotions can be understood as the result of the satisfaction or thwarting of BPN (Ryan and Deci, 2001; Flunger et al., 2013; Løvoll et al., 2020). For example, a student will experience enjoyment during the learning process if they feel competent to meet the demands of the task and value what he or she is learning (Pekrun and Stephens, 2010), as previously shown in PE classes (Leisterer et al., 2019; Fierro-Suero et al., 2020a). Thus, depending on whether teachers establish supportive or controlling interpersonal styles for the BPN in the learning environment, the BPN will be satisfied or thwarted and simultaneously autonomous motivation and positive or negative emotions will be aroused (e.g., Yoo, 2015; Bordbar, 2019). Finally, both emotions and the different types of motivational regulations have been shown to have the ability to predict the outcomes mentioned above (e.g., Fierro-Suero et al., 2022).

Recently, in different educational contexts, models based on the support of BPN have been proposed (e.g., Yoo, 2015; Bordbar, 2019; Liu et al., 2021; Zimmermann et al., 2021). These studies have advanced our understanding of the interrelationship and connection between SDT and emotional aspects. From these studies it is concluded that interpersonal style affects students emotionally and that, in turn, this has different consequences. However, most of these studies (e.g., Yoo, 2015; Bordbar, 2019; Zimmermann et al., 2021) have only considered different forms of autonomy support, ignoring the rest of BPN. On the other hand, the mediating role that BPNs can play between the teacher's interpersonal style and emotions has not been studied so far. In conclusion, studies conducted do not take into account the full bright pathway (motivating style) of the SDT sequential model (BPN support ➔ BPN satisfaction ➔ motivation ➔ outcomes; Vasconcellos et al., 2020) or have established a chronological ordering of the motivation and emotion (e.g., Yoo, 2015).

1.4. The importance of gender in PE

In recent years, the importance of gender in understanding the experience of students during PE classes has been highlighted. Aspects related to the teacher's gender and its stereotypes (Preece et al., 2022), the relationship with the teacher (van Aart et al., 2017) or the degree of physical competence (Cairney et al., 2012; van Aart et al., 2017) have been shown to affect each gender differently, ultimately impacting the students' experience during classes. For this reason, it is necessary to take into account the gender of the students in this study, as the aforementioned factors are closely related to both SDT (Deci and Ryan, 1985; Ryan and Deci, 2017) and CVTAE (Pekrun, 2006).

1.5. Outcomes in PE

Two of the most studied outcomes that have a direct relationship with what is experienced in the PE classroom are academic achievement and the intention to be physically active. On the one hand, academic achievement is influenced by several factors highlighting the role of emotions (Pekrun et al., 2017; Fierro-Suero et al., 2023) and motivation (Cheon et al., 2012; Ulstad et al., 2016). Academic achievement can be defined as a "product achieved by students in educational institutions and that is normally expressed through school grades" (Fraile-García et al., 2019, p. 58). On the other hand, one of the main aim of PE should be to prepare children for a lifetime of physical activity (Leisterer et al., 2019). The intention expressed by student to practice physical activity can be a good predictor of this behavior (Ajzen, 1991). This intention has been predicted by autonomous motivation (Vasconcellos et al., 2020) and positive emotions (Fierro-Suero et al., 2023) in previous research.

1.6. The present study

This study includes the role of positive and negative emotions in the bright pathway of SDT. This novelty represents an advance on previous studies and will help to understand to what extent the outcomes may be due to one construct or the other. Based on the established principles, the objective of this study was to examine the role that emotions and motivation play on the intention to perform future PA and on academic achievement in PE. For this, a mediated effect model was tested that suggests that the teachers' support of the students' BPN will satisfy the students' BPN (hypothesis 1), and in turn, that satisfaction predicts both the autonomous motivation and the emotions (positive and negative) of the students (hypothesis 2). Finally, autonomous motivation and positive emotions will positively predict both intention to practice in the future and academic achievement, while negative emotions will negatively predict intention to practice in the future and academic achievement of students (hypothesis 3). Likewise, the mediating role of BPN satisfaction is examined, as well as motivation and emotions in these relationships (see Figure 3). In this sense, BPN satisfaction will mediate the relationship between teacher's support for BPN and motivation and emotions, while autonomous motivation and emotions will mediate the relationship between satisfaction of BPN and intention to practice in the future and academic achievement in PE (hypothesis 4). Since SDT and CVTAE have been shown to be independent of the gender of the students (Goetz et al., 2008; Guérin et al., 2012), we hypothesized that the model including the emotions in the complete SDT sequence, is gender independent (hypothesis 5), although there could be differences in the emotions and motivational regulations experienced between the two genders.

2. Method

2.1. Design section

This research had a non-experimental quantitative, correlational and cross-sectional design (Ato et al., 2013).

2.2. Participants

The participants in this study were a convenience sample of 799 high school students (371 males and 428 females) aged 11–17 years (M = 13.16; SD = 1.17). Students were recruited from one private and four public high schools in a province in the south-west of Spain. The respondents were 253 students of first graders, 283 s graders, 207 third graders, and 56 fourth graders. PE lesson were two 60-min compulsory and coeducational per week. The PE curriculum implemented in Spain educational law is focused on the teaching of games and sports, teaching of corporal expression, development of physical and motor condition, development of health and quality of life and teaching of physical activities in the natural environment.

2.3. Measures

2.3.1. Teacher support for basic psychological needs

The *teacher support for basic psychological needs* was assessed using the scale developed by Sánchez-Oliva et al. (2013). This scale consists of a total of 12 items, four for each BPN: *Autonomy* (e.g., "Often asks us about the activities we want to do"), *competence* (e.g., "Encourages us to trust our ability to complete the tasks well"), and *relatedness* (e.g.," Always fosters good relationships between classmates"). Items are preceded by the stem "In my Physical Education class, the teacher..." The responses to the items are given on a Likert-type scale from 1 (Strongly disagree) to 5 (Strongly agree). Evidence for the reliability and validity of this questionnaire has been previously provided (e.g., Sevil-Serrano et al., 2020; Fierro-Suero et al., 2020b).

2.3.2. Satisfaction of basic psychological needs

The *satisfaction of basic psychological needs* was assessed using the scale developed by Moreno et al. (2008). The scale consists of 12 items grouped into three sub-scales of four items each: the *need for autonomy* (e.g., "I feel very strongly that I have the opportunity to make choices about the way I exercise"), the *need for competence* (e.g., "I feel that exercise is an activity in which I do very well"), and the *need for relatedness* (e.g., "I feel very much at ease with the other exercise participants"). The scale begins with the stem "In my Physical Education class …," and the answers are from a Likert scale ranging from 1 (Strongly disagree) to 5 (Strongly agree). Previous studies have tested this instrument's reliability and validity (e.g., Gil-Arias et al., 2017; González-Cutre et al., 2020).

2.3.3. Autonomous motivation

The Spanish version (Ferriz et al., 2015) of the *Perceived Locus of Causality Scale* (Goudas et al., 1994) was used to assess *autonomous motivation*. This scale includes 12 items encompassing three sub-scales of four items each: *intrinsic regulation* (e.g., "Because Physical Education is fun"), *integrated regulation* (e.g., "Because it is in line with my way of life") and *identified regulation* (e.g., "Because I want to learn sports skills"). The scale begins with the stem "I take part in Physical Education …" and the items are answered on a 7-point Likert-type scale ranging from 1 (Strongly disagree) to 7 (Strongly agree). Evidence for the reliability and validity of this questionnaire has been provided in the PE context (e.g., Gil-Arias et al., 2017; Franco et al., 2021).

2.3.4. Achievement emotions

Positive and negative emotions were evaluated with the version for *Physical Education of the Achievement Emotions Questionnaire* (Fierro-Suero et al., 2020a). This questionnaire contains 24 items grouped into six sub-scales (two positive and four negative emotions) of four items

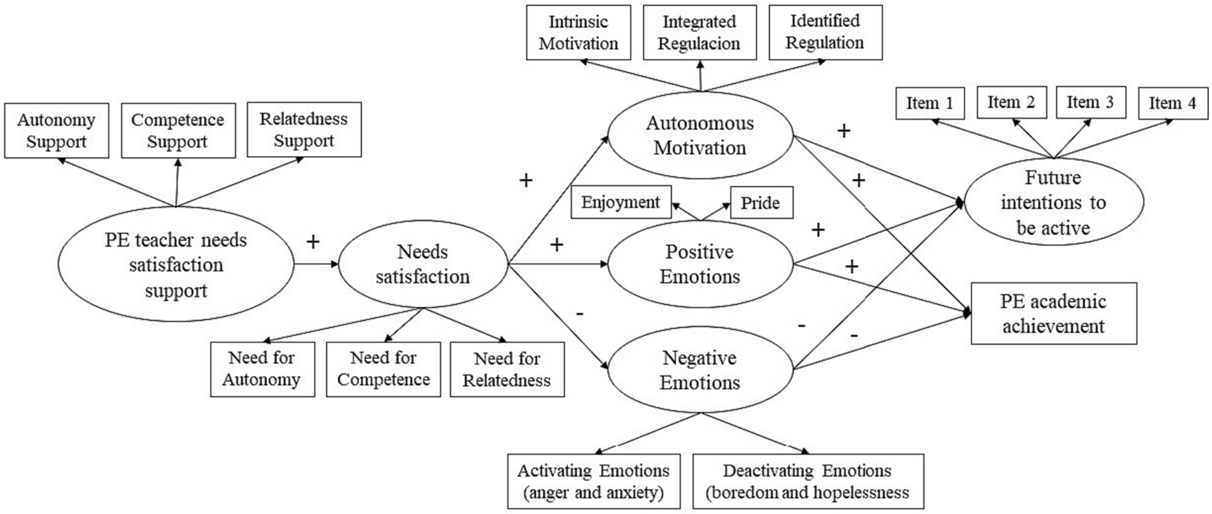

FIGURE 3
Hypothesized structural model of the associations between PE students' perceptions of their teacher's support for satisfaction of their needs, the satisfaction of their needs, autonomous motivation, positive and negative emotions, future intention, and PE academic achievement.

each: *Pride* (e.g., "I am proud of my participation in physical education class"), *enjoyment* (e.g., "I enjoy being in the physical education class"), *anger* (e.g., "I feel anger welling up in me during the physical education class"), *anxiety* (e.g., "I feel nervous in the physical education class"), *hopelessness* (e.g., "It is pointless to prepare for the physical education class because I am bad at it anyway"), and *boredom* (e.g., "I get bored during the physical education class"). The responses to the items are given on a Likert scale ranging from 1 (Strongly disagree) to 5 (Strongly agree). Evidence for the reliability and validity of this questionnaire has been previously provided (e.g., Fierro-Suero et al., 2022, 2023).

2.3.5. Intention to be physically active

The *intention to be physically active* was evaluated with the Spanish version (Moreno et al., 2007) of the *Intention to be Physically Active Scale* (Hein et al., 2004). This scale consists of 5 items (e.g., "I would like to be physically active") preceded by the stem "Regarding my intention to practice sport or physical activity in my free time ….". The responses to the items are given on a Likert-type scale ranging from 1 (Strongly disagree) to 5 (Strongly agree). The reliability and validity of this questionnaire have been confirmed previously (e.g., Fernández-Espínola et al., 2020; Merino-Barrero et al., 2020).

2.3.6. Academic achievement in physical education

To measure *academic achievement in PE*, the participant's score (0–10) on their last final PE assessment was used. This score was decided by the teachers based on the evaluation criteria established in the educational laws in Spain for PE. This method has been used in previous studies (e.g., Pekrun et al., 2009; Hagen et al., 2021).

2.4. Procedure

This study was conducted in accordance with the ethical principles of the American Psychological Association and was approved by the Andalusian (Spain) Ethics Committee for Biomedical Research (TD-OCME-2018). First, the researchers directly contacted school administrators and school boards to inform them and request their cooperation in the research. As the students were minors, written authorization was requested from both the school and the parents of the participants. A member of the research team was present during the administration of the questionnaire. The questionnaires were answered anonymously and administered in a classroom setting. The students participated voluntarily and took approximately 30 min to complete the questionnaires. To avoid possible biases in participant's responses, we eliminated those students who completed the test in less than half the time than the group average and those who filled in all responses with the same score.

2.5. Data analysis

Descriptive statistics (mean, standard deviation, skewness, kurtosis), bivariate correlations and internal consistency (Cronbach alpha and Omega coefficients) were analyzed using PROCESS MACRO version 3.0 (Hayes and Coutts, 2020) for IBM SPSS Statistics version 20 (IBM Corp. Armonk, NY, USA). We performed a hypothesis contrast test using the Fisher r to z transformation to examine whether the correlations between the hypothesized model variables were similar between males and females. In the case of finding differences by gender, we would analyze the gender invariance of the hypothesized model. The percentage of missing data was very small (< 0.05%). To examine the factorial structure of each instrument and to test the study hypotheses (see Figure 3), we used Mplus version 8 (Muthén and Muthén, 2017). We ran a mediated regression model and, to verify the fit of the models, we considered the chi-square, the Tucker-Lewis Index (TLI), the Comparative Fit Index (CFI), the Root Mean Square Error of Approximation (RMSEA), and the Standardized Root Mean Square Residual (SRMR), Average Variance Extracted (AVE) and Composite Reliability (CR). Values of TLI and CFI above 0.90 indicate an acceptable fit. For RMSEA and SRMR, values equal or below 0.08 are considered satisfactory (Hu and Bentler, 1999). For AVE and rho values above 0.50 and 0.70 indicates a good score reliability (Fornell and Larcker, 1981; Raykov, 2001). The Mardia's coefficient was calculated (57.20) indicating multivariate non-normality in the data (Satorra and Bentler, 1994). So, the structural models were tested using maximum likelihood as the estimation method and modeling the relationships among the observed. To test the mediated or indirect effects, we used the bias-corrected bootstrap confidence interval method as implemented in Mplus. If the confidence interval does not include zero, the null hypothesis of no mediation is rejected, providing empirical support for the indirect effect.

The gender invariance testing of the model involved two hierarchically ordered steps. First, the *a priori* factor structure was fitted separately for each gender to determine the extent to which the reference model fit the data for each gender separately. Second, the configural invariance model tested the invariance of the hypothesized relationships of the model across seasons, but no invariance constraint was imposed in any parameters. This model was used as a baseline for fit comparisons against the later, more restricted model. Finally, a total invariance model addressed the equality of all parameters across gender. Thus, this model tested whether all relationships between the variables in the model remained invariant across the two genders. With the aim of assessing the fit for the models, the same modeling rationale we employed to test mediation effect of the needs and emotions was used.

Due to the number of parameters in the hypothesized model, we used means scores of three indicators of the *support for basic psychological needs (autonomy support, competence support and relatedness support)*, means scores of three indicators of the *satisfaction of the basic psychological needs (needs for autonomy, competence and relatedness)*, means scores of three indicators of *autonomous motivation (intrinsic, integrated and identified regulations)*, means scores of two indicators of *positive emotions (enjoyment and pride)*, means scores of two indicators of *negative emotions (activating negative emotions: anger and anxiety*; and *deactivating negative emotions: boredom and hopelessness)*, four items for future *intention to be physically active*, and one item for *academic achievement* (see Figure 3). So, seven observed variables were included in the model.

3. Results

The results of the factorial structure of the instrument used offered acceptable fit indices (see Table 1). The descriptive statistics (range, mean, standard deviations, skewness and kurtosis) and internal consistency of the study variables appear in Table 2. Descriptive statistics for all study indicators can be found in Supplementary Table S1. The participants exhibited moderate average scores, above the response scale's nominal midpoint on all the variables (except for negative emotions). All the variables showed acceptable alpha and omega coefficients (see Table 2). All the study variables, that is, support for basic psychological needs, satisfaction of basic psychological needs, autonomous motivation, positive emotions, intention to be physically active in the future and academic achievement (except for negative emotions) were positively correlated between themselves, and all these variables were negatively correlated with negative emotions (see Table 2).

The results for gender differences in the correlations showed that there were no significant differences ($z < 1.96$) in the majority of the studied variables (see Table 3). However, the differences found are precisely in the relationships with the outcome variables, so we tested the hypothesized model analyses on boys and girls individually (see Figure 3).

The hypothesized structural model for boys [χ^2 (125) = 474.91, $p = 0.001$, TLI = 0.900; CFI = 0.911; SRMR = 0.055; RMSEA = 0.087] and girls [χ^2 (125) = 524.89, $p = 0.001$, TLI = 0.901; CFI = 0.919; SRMR = 0.050; RMSEA = 0.086] showed an adequate fit to the data. Next, the configural invariance model was tested by analyzing the invariance of the factor structure without putting restrictions on the parameters, and the fit was satisfactory [χ^2 (250) = 906.77, $p = 0.001$, TLI = 0.900; CFI = 0.915; SRMR = 0.056; RMSEA = 0.061]. Consequently, this model was used as a baseline for comparison with the total invariance model, where the restriction of equality in all parameters is assumed in the two samples. The total invariance model had an adequate fit [χ^2 (277) = 943.13, $p = 0.001$, TLI = 0.903; CFI = 0.913; SRMR = 0.078; RMSEA = 0.059]. Differences not larger than 0.01 between TLI and CFI values are considered an indication of negligible practical differences (Cheung and Rensvold, 2002). For RMSEA and SRMR, values equal to or lower than 0.08 are optimal (Cole and Maxwell, 1985). The results showed that the models compared showed acceptable fit indices, with no significant differences between the model without restrictions and the model with total restriction, which supports the existence of model invariance in both groups. The standardized parameter estimates are shown in Figure 4.

The results revealed partial support for the hypothesized model. Perceptions of *PE teacher support for satisfaction of psychological needs* were positively and highly related to *satisfaction of basic psychological needs.* In line with the proposed model, there was a significant and positive path between *satisfaction of needs* and *autonomous motivation*, and *positive emotions*, and negatively with *negative emotions. Autonomous motivation* was positively and moderately related to *intentions to be physically active in the future* and weakly related to *PE academic achievement*. The paths between *positive and negative emotions* with *future intention* were not significant. Finally, *positive emotions* were weakly significant and positively related to *PE academic achievement*, whereas the relation between *negative emotions* and *PE academic achievement* was significant and negative (see Figure 4). The results of the proposed model significantly predicted 51% of the variance in reported *intention to be physically active in the future* and 22% of the variance in reported *PE academic achievement*.

Finally, we analyzed the indirect effects (IE) of the *PE teacher support for satisfaction of needs* on *intentions to be active in the future* and *PE academic achievement* through *satisfaction of needs, motivation and emotions (positive and negative)*. The IE on *intentions to be active in the future* through *satisfaction of needs* and *autonomous motivation* was positive and statistically significant (IE = 0.26; bootstrap CI 95% = [0.21, 0.31]). The IE on *PE academic achievement* through *satisfaction of needs* and *autonomous motivation* was also positive and statistically significant (IE = 0.16; bootstrap CI 95% = [0.08, 0.24]). The *IE on PE academic achievement* through *satisfaction of needs* and *positive emotions* was positive and statistically significant (IE = 0.10; bootstrap CI 95% = [0.01, 0.18]). Finally, the IE on *PE academic achievement* through *satisfaction of needs* and *negative emotions* was also positive and statistically significant (IE = 0.12; bootstrap CI 95% = [0.06, 0.18]). These results provide total support for the indirect

TABLE 1 Goodness-of-fit indices for the study instruments.

	$\chi2$	*df*	CFI	TLI	RMSEA	SRMR	AVE	CR
Basic needs support	226.46	51	0.97	0.96	0.06	0.03	0.56	0.94
Basic needs satisfaction	283.34	51	0.94	0.92	0.07	0.06	0.52	0.93
Autonomous motivation	342.58	51	0.96	0.94	0.08	0.03	0.61	0.95
Achievement emotions	928.39	245	0.92	0.91	0.06	0.06	0.53	0.91
Future intention	13.85	2	0.96	0.96	0.08	0.02	0.50	0.80

For all χ^2 values, $p < 0.01$; df, degrees of freedom; CFI, comparative fit index; TLI, Tucker–Lewis index; RMSEA, root mean square error of approximation; SRMR, standardized root mean residual; AVE, average variance extracted; CR, composite reliability.

TABLE 2 Descriptive statistics, internal consistency, and bivariate correlations between study variables.

Variable	1	2	3	4	5	6	7
1. Basic needs support	-						
2. Basic needs satisfaction	0.58**	-					
3. Autonomous motivation	0.57**	0.71**	-				
4. Positive emotions	0.55**	0.71**	0.73**	-			
5. Negative emotions	−0.43**	−0.58**	−0.52**	−0.64**	-		
6. Future intention	0.25**	0.50**	0.59**	0.47**	−0.34**	-	
7. Academic achievement	0.30**	0.40**	0.40**	0.40**	−0.38**	0.29**	-
Range	1–5	1–5	1–7	1–5	1–5	1–5	0–10
Mean	3.71	3.69	5.39	4.03	1.66	4.13	7.53
Standard deviation	0.85	0.71	1.27	0.82	0.59	0.90	1.56
Skewness	−0.87	−0.65	−0.90	−1.01	1.65	−1.10	−0.59
Kurtosis	0.35	0.17	0.42	0.68	3.51	0.75	−0.17
Alpha	0.92	0.87	0.94	0.89	0.87	0.77	-
Omega	0.92	0.87	0.94	0.88	0.87	0.77	-

**$p < 0.001$.

effect of the *PE teacher's support for satisfaction of needs* on *intentions to be physically active in the future* and *PE academic achievement* through s*atisfaction of needs* and *autonomous motivation*, and the partial support through *satisfaction of needs* and *emotions* on *PE academic achievement* but not on *intentions to be physically active in the future*.

4. Discussion

The objective of this study was to find the role that emotions and motivation in PE classes play on academic achievement and the intention to practice PA in the future. To date, studies conducted to explain these outcomes have focused mainly on student motivation (e.g., Ulstad et al., 2016; Franco and Coterón, 2017; Castillo et al., 2020). However, despite the fact that emotions give us important information about human behavior (Meyer and Turner, 2006) and the significant impact on the educational context (Ramirez-Arellano et al., 2019; Järvenoja et al., 2020), there have been few studies of this construct. In recent years, different investigations have shown that both CVTAE at an emotional level (Simonton and Garn, 2020; Zimmermann et al., 2021; Fierro-Suero et al., 2023) and SDT at the motivational level (Franco and Coterón, 2017; Castillo et al., 2020) are able to explain outcomes in PE classes. Currently, there are few investigations that jointly analyze the motivational and emotional roles without prioritizing one construct above the other in PE classes. For this, in this study, the integration of emotions in SDT has been proposed following the common postulates between CVTAE and SDT. Thus, the hierarchy of one construct over the other is avoided, allowing for both clearly influencing human behavior (Reeve, 2010).

The analysis of the structural equations model confirmed hypothesis 1 since the support of the BPN by the teacher in the learning environment acted as a predictor of the satisfaction of the students' BPN. These results have been widely supported by previous scientific literature (Vasconcellos et al., 2020). For the study's second hypothesis, the proposed model showed that satisfaction of BPN was a significant predictor of both autonomous motivation and emotions (positive and negative), confirming hypothesis 2. Different studies have shown that satisfaction of BPN provokes more self-determined motivations, as established by the SDT (e.g., Haerens et al., 2015; Franco and Coterón, 2017). Although this theory does not explicitly include the emotional role in its sequence, it does state that the satisfaction of BPN produces positive emotions (Ryan and Deci, 2001), which has been shown in education in general (Flunger et al., 2013) and in PE in particular (e.g., Leisterer et al., 2019; Løvoll et al., 2020; Fierro-Suero et al., 2020a, 2023). In this way, as established by the CVTAE depending on the control and value appraisals, evaluations that are closely related to the BPN, some emotions or others will be generated (Pekrun and Stephens, 2010).

TABLE 3 Results of values of correlation differences across gender for the study variables.

Correlation variables	Males correlation	Females correlation	z
Basic needs support – basic needs satisfaction	0.54**	0.61**	−1.47
Basic needs satisfaction – autonomous motivation	0.66**	0.72**	−1.61
Basic needs satisfaction – positive emotions	0.69**	0.70**	−0.27
Basic needs satisfaction – negative emotions	−0.53**	−0.60**	−1.45
Autonomous motivation – future intention	0.54**	0.60**	−1.25
Positive emotions – future intention	0.32**	0.53**	−3.63**
Negative emotions – future intention	−0.25**	−0.36**	1.70
Autonomous motivation – academic achievement	0.33**	0.46**	−2.17*
Positive emotions – academic achievement	0.33**	0.45**	−1.99*
Negative emotions – academic achievement	−0.34**	−0.41**	−1.14

*$p < 0.05$; **$p < 0.001$.

Hypothesis 3 of the study has been partially fulfilled. To date, research has shown that both motivation (Ulstad et al., 2016; Franco and Coterón, 2017; Castillo et al., 2020) and emotions (Simonton and Garn, 2020; Fierro-Suero et al., 2023) independently, were able to predict academic achievement in PE and intention to be active in the future. In this sense, the results of this study have shown that the intention to be physically active in the future was only predicted by autonomous motivation, with the effect of emotions experienced during PE classes having a lesser effect. These results are consistent with those found by Løvoll et al. (2017) who showed that, despite the fact that positive emotions and intrinsic motivation both acted as predictors of the choice of future PA, by including both variables in the regression model the emotional effect is completely reduced. The intention of future PA is based on a subjective perception that requires a reflective process. On the one hand, this process is closely related to the orientation, management and persistence over time of the behavior, that is, to the definition of motivation (Reeve, 2010). On the other hand, it requires more extensive cognitive processing and, therefore, a deliberation associated more with motivational behaviors than with emotional ones (Roseman, 2013). Another aspect to consider is that emotions are situation specific, the perceptions of control-value that one develops in a specific context are what form an emotional response to that specific context (PE in this case), therefore, extracurricular PA may be quite different from PE experiences. Momentary emotions are associated with specific behaviors, such as anger with aggressive reactions or boredom with disinterest, which can affect academic achievement. The assessment of practicing physical-sports activity could be too generic a behavior to be affected by the achievement emotions experienced during the classes. Along these lines, Løvoll et al. (2017) found that emotions played a different role in predicting outdoor PA or in choosing a sport. Thus, it makes sense to think that the intention to practice in the future is explained more by autonomous motivation than by emotions, as the results obtained have indicated.

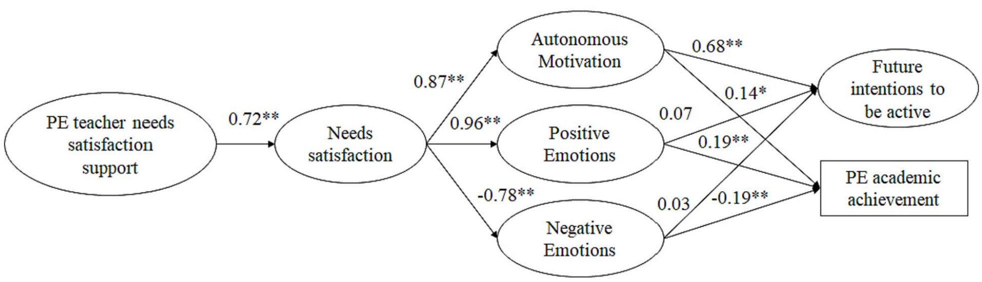

FIGURE 4
Gender-invariant structural. All coefficients are standardized. Factor indicators are not shown for reasons of simplicity of presentation. **$p < 0.01$; *$p < 0.05$.

For its part, academic achievement is an objective measure provided by teachers that does not require the reflective process on the part of the students mentioned above. So far, the importance of emotions on academic achievement has been shown (Pekrun et al., 2009; Fierro-Suero et al., 2023) as they directly affect the specific behaviors of students during classes (Roseman, 2013; Simonton and Garn, 2020) impacting on the teachers' assessment of them. Although, to a lesser extent than emotions, autonomous motivation also acted as a predictor of academic achievement, as confirmed by previous studies (Cheon et al., 2012; Ulstad et al., 2016). Therefore, it could be concluded that motivation plays a more significant role in explaining the future intention to practice PA and emotions play a more decisive role in students' academic achievement. This may be because motivational behavior is more deliberate and prolonged (Roseman, 2013) and can be extrapolated toward its intention for the future. However, emotional behavior, being more sporadic, has a more short-term effect, which can affect behaviors that occur over a short space of time to a greater extent.

Therefore, the results of the structural equation model and the indirect effects confirm hypothesis 4. These show that the sequence proposed, in which the emotional and motivational roles are integrated, following the principles of the CVTAE and SDT, is consistent and opens an avenue for future research. It will be interesting to include into the model in the future other variables related to both theories' postulates, such as self-efficacy expectations, attributions of achievement, the teacher's controlling style, thwarting of BPN, etc. Advancing along these lines will mean going into greater depth for the interrelation between motivation and emotion and the repercussions of these during the classes.

The results confirmed that the proposed model is gender-independent, confirming hypothesis 5. However, it is interesting to highlight the gender differences found in the relationships (correlations differences across gender) of motivation and emotions to the two outcomes studied (intention to practice PA in the future and academic achievement). These results seem to indicate that, as has recently been shown (Fierro-Suero et al., 2023), the imprint of what is experienced during the classes conditions the behavior of girls more than boys. As the authors argue, this could be due to various factors such as the difference in character between boys and girls (Chaplin and Aldao, 2013), the role of the teacher and their stereotypes (Preece et al., 2022), or the lower level of after-school PA in girls (Lodewyk and Muir, 2017). This last factor could allow the extracurricular PA experience, more notable in boys than in girls, to compensate for the assessment made of sport and PA (Fierro-Suero et al., 2023). Thus, for those students who do not do after-school PA, PE is the most important physical experience (Shephard, 2008) and therefore, their assessment of what happened may condition the outcomes studied to a greater extent. Expanding the outcomes analyzed taking into account both constructs should be a priority. This would allow the preparation of interventions that help to find effective and efficient strategies to improve educational quality, which should be a priority for researchers and teachers.

4.1. Practical implications

The present findings have important implications for current theorizing, research, and practice on motivational and emotional teaching. Emotions have been integrated into SDT model, which represents a significant advance compared to previous research. Simultaneous examination of motivations and emotions in students has shown how it is possible to differentiate in terms of individual perceptions (Ramirez-Arellano et al., 2019; Van Roekel et al., 2019) as well as the consequences of these, despite the difficulty of differentiating between motivational and emotional aspects of teaching styles (Meyer and Turner, 2006). Therefore, having a supportive interpersonal motivational style helps to improve both students' motivations and emotions. To improve interpersonal style, it is recommended to consult the recent classification made by a wide panel of international experts (Ahmadi et al., 2023). Based on the present results and previous studies (e.g., Fierro-Suero et al., 2020a; Zimmermann et al., 2021) it would be interesting to complement the motivational style (based on SDT) with the recommendations on how to improve emotional perception in PE classes from the latest studies developed (e.g., Simonton and Garn, 2018, 2020; Fierro-Suero et al., 2023).

4.2. Limitations and future work

This study has some limitations. First, we used a correlational and cross-sectional design, which prevents us from considering causal relationships. Second, most of the information collected was self-reported, with the exception of academic achievement, and no information was collected from the teacher on his or her perception of support for the students' basic psychological needs. Due to the number of variables collected, in the hypothesized model we have had to group the emotions according to the degree of activation and valence. Although this may represent a loss of value, at the same time it provides a basis for future research to address these relationships more specifically. Finally, we have only considered the bright pathway of the SDT. It could be interesting in the future to carry out studies from the SDT dark pathway (demotivating style) or to consider other variables related to CVTAE, the gender of teachers, the age range between teachers and students, as well as longitudinal studies, which would allow us to contrast it with the results obtained in this study.

5. Conclusion

In conclusion, this study has shown the importance of including both motivation and emotions to understand the consequences of what happens in PE classes. Thus, when jointly studying motivation and emotion, following the theoretical principles of the SDT, it has been found that motivation plays a more significant role in explaining the intention to practice PA in the future outside school. However, although motivation is also important, the emotions experienced by students explain their academic achievement to a greater extent. It is essential to continue advancing along this line as a first step to establishing more effective strategies to improve educational quality.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author based on reasonable request due to ethical restrictions.

Ethics statement

The studies involving humans were approved by Andalusian (Spain) Ethics Committee for Biomedical Research (TD-OCME-2018). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the minor(s)' legal guardian/next of kin for the publication of any potentially identifiable images or data included in this article.

Author contributions

IC, BA, and PS-L: conceptualization, supervision, and validation. SF-S: data curation. SF-S and IC: formal analysis, funding acquisition and writing – original draft. SF-S, IC, and BA: investigation and software. SF-S and PS-L: methodology. SF-S, IC, and PS-L: project administration. SF-S, IC, BA, and PS-L: resources, visualization, and writing – review and editing. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1253043/full#supplementary-material

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Psychometric properties of the Chinese version of Sport Anxiety Scale-2

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Introduction: The Sport Anxiety Scale-2 (SAS-2) is a validated measure of sports trait anxiety, with promising psychometric properties. However, its cross-cultural applicability in Chinese samples remains unexplored. Thus, the primary objectives of this study were twofold: to translate the SAS-2 into Chinese and assess the psychometric properties of the Chinese version.

Methods: In Study 1, we initiated the translation of the SAS-2 into Chinese. This assessment involved bilingual Chinese students proficient in both English and Chinese. Additionally, we conducted a cross-linguistic measurement invariance analysis. In Study 2, we delved into the psychometric properties of the Chinese SAS-2 using a sample of Chinese student athletes. This examination encompassed an evaluation of its factor structure, convergent and discriminant validity, and measurement invariance across genders.

Results: Our findings in Study 1 indicated no significant differences in item scores between the Chinese SAS-2 and the English version, and measurement invariance across languages. In Study 2, we uncovered that the Chinese SAS-2 and its factors exhibited excellent reliability, with Cronbach's alpha values exceeding 0.80. Confirmatory factor analyses upheld the original three-factor model, demonstrating acceptable model fit indices (CFI = 0.96, TLI = 0.93, RMSEA = 0.08). Furthermore, all three factors of the Chinese SAS-2 displayed significant and positive correlations with athlete burnout and State-Trait anxiety. Additionally, this study elucidated the mediating role of Concentration Disruption (Somatic anxiety and Concentration Disruption) in the relationship between the Trait (State) anxiety, and athlete burnout. Moreover, we identified measurement invariance of the Chinese version of the SAS-2 across genders. Finally, female college athletes exhibited significantly higher scores in somatic anxiety and worry compared to their male counterparts.

Discussion: In sum, our findings affirm that the Chinese version of the SAS-2 demonstrates robust reliability and correlates effectively with related criteria, thus validating its suitability for use in a Chinese context.

KEYWORDS

Sport Anxiety Scale-2 (SAS-2), cross-cultural adaptation, psychometrics, confirmatory factor analyses, competitive anxiety

Introduction

Anxiety is an emotion characterized by unpleasant feelings of tension, worrying thoughts, and corresponding physical symptoms (Spielberger, 2013). For example, in response to a perceived threat, the body typically mobilizes itself by tensing muscles, increasing breathing rate, and raising heart rate. Anxiety is not only closely related to well-being (Shek, 1993; Weidman et al., 2012) but also exerts a significant impact on our cognitive abilities (Eysenck and Calvo, 1992; Maloney et al., 2014) and sports activities (Krohne and Hindel, 1988). For instance, previous meta-analyses examining the relationship between anxiety and athletic performance have consistently found a significant and negative correlation. Furthermore, this meta-analysis has identified gender and age as moderators influencing the magnitude of this effect (Woodman and Hardy, 2003).

Competitive anxiety

Within the realm of sports, athletic competitions tend to be inherently anxiety-inducing and feel stressed. For example, previous research conducted by Di Corrado et al. (2021) has found that psychological stress in elite canoe polo players plays a fully mediating role in mood and performance. As a result, anxiety has become a prominent area of focus within sports psychology, garnering attention from numerous researchers (Woodman and Hardy, 2003), particularly in relation to anxiety and sports performance. Competitive anxiety refers to the sport-specific anxiety experienced by individuals before or during competitive events (Martens, 1977). Researchers have also developed measurement instruments specifically tailored to assess trait anxiety in sports, aiming to quantify competitive anxiety (Martens, 1977; Smith et al., 1990).

Martens (1977) was the first to develop a unidimensional measurement tool called The Sport Competition Anxiety Test (SCAT). Subsequent studies have demonstrated the SCAT's good reliability and validity across various samples (Cheatham and Rosentswieg, 1982; Brand et al., 1988). However, it is worth noting that the SCAT does not differentiate between somatic and cognitive anxiety or measure the differences between them. Afterward, Martens et al. (1980) developed the Competitive State Anxiety Inventory (CSAI) to evaluate self-confidence, as well as the physical and cognitive aspects of anxiety linked to a forthcoming competition. To comprehensively evaluate the multifaceted nature of anxiety, Martens et al. (1990) introduced the Competitive State Anxiety Inventory-2 (CSAI-2). This inventory was designed to gauge cognitive anxiety, somatic anxiety, and self-confidence. In addition, researchers developed the Sport Anxiety Scale (SAS) and its subsequent version, the SAS-2, as multidimensional measures of sport-specific trait anxiety. The SAS were based on the antecedents and consequences of cognitive and somatic anxiety (Smith et al., 1990, 2006). In the CSAI-2 and SAS-2, the CSAI-2 emphasizes the situational occurrence of the phenomenon, while the SAS-2 concentrates on sport-specific trait anxiety. Therefore, the present study will concentrate on the SAS-2, which assesses sport-specific trait anxiety, instead of the CSAI-2.

The Sport Anxiety Scale (SAS)

Regarding the SAS, Smith et al. (1990) created a 21-item version of the scale, drawing from the cognitive-emotional model of anxiety and relevant empirical research. The development process involved exploratory and confirmatory factor analyses for cross-validation purposes. The scale was employed to assess an individual's somatic anxiety, worry and concentration disruption. A previous study demonstrated a negative correlation between concentration disruption scores and the performance of college football players throughout a season (Smith et al., 1990). The multidimensional SAS may contribute to a clearer definition of sport-related anxiety and provide a more comprehensive understanding of the sport anxiety profile.

However, subsequent research revealed that the SAS might not be suitable for younger age groups (Smith et al., 1995). As a result, Smith et al. (2006) further revisions and developed the SAS-2, which comprises 15 items. Through exploratory and confirmatory factor analyses, the study successfully replicated the original SAS factor structure across various age levels. Notably, in the 9-to 10-year-old sample, three distinct subscales emerged: Somatic Anxiety, Worry, and Concentration Disruption. Importantly, the scale reliably predicted pre-competition state anxiety scores and demonstrated sensitivity to anxiety reduction interventions aimed at youth sport coaches (Smith et al., 2006). The SAS-2 has also exhibited strong psychometric properties in both child and adult samples, further validating its efficacy (Grossbard et al., 2007, 2009).

Cross-cultural study of the SAS-2

As a result, the SAS-2 has been translated into different languages and its psychometric properties have been validated by researchers in several countries (Ramis et al., 2010; Silva-Rocha et al., 2019; Tomczak et al., 2022). As an example, Ramis et al. (2010) translated the SAS-2 into Spanish and determined that the Spanish version demonstrated good psychometric properties among child and adolescent athletes [Three-factor structure confirmatory factor analysis (CFA) model fit index: comparative fi t index (CFI) = 0.98, tucker-Lewis index (TLI) = 0.99, root-mean square standard error of approximation (RMSEA) = 0.05]. Following that, Silva-Rocha et al. (2019) examined the psychometric properties of the Brazilian version of the SAS-2 in professional and amateur athletes. The study's findings revealed that the fit indices for the original three-factor model (Smith et al., 2006) did not reach a satisfactory level (CFI = 0.91, TLI = 0.90, RMSEA = 0.125). Subsequently, the correlation between the item 6 and item 12 errors was introduced into the original three-factor model, resulting in a notable improvement in the model's fit indices (CFI = 0.97, TLI = 0.96, RMSEA = 0.08). Moreover, Ramis et al. (2015) collected data on three versions of the SAS-2 in Spain, Belgium, and Portugal, involving 842 athletes. The study found that the SAS-2 factorial model demonstrated invariance across gender, age, and sport type, underscoring its robustness and consistency across these variables. Moreover, CFI and TLI consistently exceeded 0.95, while RMSEA remained below 0.04 in the three-factor correlation CFA model.

Within the East Asian cultural context, the SAS-2 has been translated into different versions, such as the Malaysian version (Hashim et al., 2017), the Korean version (Cho et al., 2018), and the Indonesian version (Putra et al., 2021). These studies have found that the different language versions of the SAS-2 exhibit good psychometric properties within their respective languages. For instance, in the Hashim et al. (2017) study, the model fit indices for CFA were CFI = 0.93 and RMSEA = 0.06. Similarly, in the Putra et al.

(2021) study, the CFA model exhibited CFI = 0.923, TLI = 0.91, and RMSEA = 0.08. As a result, they are considered valid and reliable measures for assessing anxiety levels. However, to date, there is a lack of cross-cultural validation of the SAS-2 among Chinese samples. Importantly, no study has translated the complete SAS-2 into Chinese and examined its applicability in China, which is the largest among the East Asian countries.

The present study

As previously mentioned, there is a lack of validation for the SAS-2 among Chinese samples. It is still uncertain whether the Chinese version of the SAS-2 exhibits similar psychometric properties to the English version and whether it can effectively be applied to a Chinese sample. Therefore, the primary objective of the present study was to translate and cross-validate the psychometric properties of the SAS-2 in a Chinese sample. In Study 1, drawing upon prior cross-cultural research on scale instruments, we initially crafted and validated the Chinese version of the SAS-2 through a test–retest study involving a bilingual sample (Shou et al., 2017). Additionally, we conducted a multi-group CFA to assess measurement invariance between the Chinese and English SAS-2 versions (Ramis et al., 2015).

In Study 2, we scrutinized the psychometric properties of the Chinese version of the SAS-2 in a large sample of Chinese student-athletes. Firstly, we conducted an analysis to assess the reliability of the Chinese SAS-2 version. Subsequently, we examined the outcomes of fitting the original three-factor model using CFA. Furthermore, we delved into investigating the convergent and discriminant validity of the SAS-2 concerning State–Trait anxiety and athlete burnout. Lastly, we explored gender-based score differences and evaluated measurement invariance.

Study 1

Study 1 aimed to translate the SAS-2 from English to Chinese, with the objective of ensuring the accurate reflection of the English version in the Chinese translation. To achieve this, the study examined the convergence between the English and Chinese versions by analyzing correlations and mean differences among the items. Furthermore, we conducted a multi-group CFA to assess measurement invariance across languages. A bilingual Chinese-English sample was utilized for this analysis.

Participants and procedures

Study 1 consisted of 91 bilingual university students who voluntarily participated in the research. Among them, 77 were females. The participants had an average age of 19.63, with a standard deviation of 1.50. All these students were majoring in English. Prior to the start of the study, participants signed an informed consent form. In the classroom setting, they completed both the English and Chinese versions of the Sport Anxiety Scale-2. The order of administering the English and Chinese versions was balanced across participants. Participants received partial compensation for their involvement in the study in the form of course credit. The research protocol was approved by the local Ethics Committee.

Measures

SAS-2 (English Original)

The SAS-2 is a 15-item scale designed to assess the level of competitive trait anxiety experienced by athletes before or during competition (Smith et al., 2006). The SAS-2 comprises three factors, namely somatic anxiety, worry, and concentration disruption, each consisting of five items. Participants rate each item on a four-point Likert scale (e.g., "My stomach feels upset"), ranging from 1 (not at all) to 4 (very much). Lower scores indicate lower intensity of competitive anxiety in that aspect, while higher scores suggest a higher likelihood of experiencing that specific type of anxiety. Previous studies have demonstrated that the SAS-2 exhibits a good factor structure and internal consistency, allowing it to be utilized in research regardless of participants' language (Ramis et al., 2015).

Chinese SAS-2

The Chinese version of the SAS-2 was translated by both the authors and bilingual students. The translation process consisted of three parts: translation from English to Chinese, translation from Chinese to English, and independent validation. Initially, the authors translated the English version of the SAS-2 into Chinese. Subsequently, bilingual students proficient in English were invited to translate the Chinese version back into English. Finally, bilingual postgraduate students proficient in English were asked to assess and compare the two English versions to ensure the translated version accurately reflected the original meaning. In cases where discrepancies in meaning arose, the described processes were repeated until all items had consistent and equivalent meaning.

Data analysis

In Study 1, we initially compared item scores between the Chinese and English versions of the SAS-2 using a paired-sample *t*-test in a sample of bilingual Chinese university students. Subsequently, we performed a multi-group CFA to assess the measurement invariance of the Chinese and English versions of the SAS-2. Specifically, in this process, we constructed three models as follows: (1) The baseline model, which we initially used to test configural invariance across groups in the original model. (2) The Metric invariance model, built upon the baseline model, introduced the constraint of invariant factor loadings to be equal for both groups. (3) Finally, the Scalar invariance model, an extension of the metric model, imposed the additional constraint of equal item thresholds across groups. One can refer to Millsap (2012) for more detailed analyses of measurement invariance. Multi-group CFA were performed in this study using "lavaan" package (version 0.6–15) in R (version 4.3.0) (Rosseel, 2012) Multiple fit indices were assessed, including the chi-square, RMSEA, TLI, and CFI. Finally, we conducted a paired-samples *t*-test using IBM SPSS Statistics version 22.0.

Results

Paired *t*-tests between Chinese and English SAS-2 item ratings

A paired-sample *t*-test was employed to compare the convergence effect between the Chinese and English versions, as shown in Table 1. As

TABLE 1 Paired samples *t*-tests and correlations between Chinese and English SAS-2 item ratings.

Items	*r*	CV (M ± SD)	EV (M ± SD)	*t*
It is hard to concentrate on the game.	0.73**	2.04 ± 0.83	2.11 ± 0.95	−0.95
My body feels tense.	0.96**	2.74 ± 0.94	2.73 ± 0.91	0.38
I worry that I will not play well.	0.79**	2.78 ± 0.95	2.80 ± 0.92	−0.34
It is hard for me to focus on what I am supposed to do.	0.69**	2.21 ± 0.91	2.18 ± 0.95	0.43
I worry that I will let others down.	0.92**	2.56 ± 0.91	2.54 ± 0.94	0.58
I feel tense in my stomach.	0.84**	2.09 ± 1.06	2.15 ± 1.02	−1.06
I lose focus on the game.	0.90**	1.99 ± 0.82	1.93 ± 0.83	1.39
I worry that I will not play my best.	0.84**	2.55 ± 0.90	2.46 ± 0.92	1.65
I worry that I will play badly.	0.92**	2.53 ± 0.90	2.49 ± 0.87	0.90
My muscles feel shaky.	0.74**	2.31 ± 101	2.29 ± 0.91	0.30
I worry that I will mess up during the game.	0.72**	2.44 ± 0.93	2.38 ± 0.90	0.76
My stomach feels upset.	0.72**	2.13 ± 1.01	2.09 ± 0.88	0.59
I cannot think clearly during the game.	0.74**	2.07 ± 0.98	2.15 ± 0.91	−1.24
My muscles feel tight because I am nervous.	0.79**	2.35 ± 0.95	2.33 ± 0.90	0.35
I have a hard time focusing on what my coach tells me to do.	0.74**	1.99 ± 0.84	2.03 ± 0.81	−0.71

EV, English version; CV, Chinese version; ***$p < 0.001$.

anticipated, both the English and Chinese versions exhibited significant correlations, with all correlations exceeding 0.60. The results of the paired-sample *t*-test indicated no significant difference (all $p > 0.05$) between the Chinese and English versions of the SAS-2 across any of the 15-item scores.

Measurement invariance analysis

We partitioned the data into two groups, one for the Chinese version of the SAS-2 and the other for the English version of the SAS-2. Subsequently, we conducted a CFA with multiple groups. The results, as presented in Table 2, initially indicate invariance across languages at the Metric invariance level. In other words, the changes in the model fit indices when compared to the baseline model were all less than 0.01 (Cheung and Rensvold, 2002). Furthermore, when we imposed the additional constraint of equal item thresholds, similar results emerged, with changes in CFI, TLI, and RMSEA between Scalar invariance and Metric invariance all remaining below 0.01. The changes in CFI, TLI, and RMSEA were all less than 0.01.

Study 2

The aim of Study 2 was to validate the Chinese version of the SAS-2 in a sample of Chinese athlete-students. The study had several objectives. Firstly, we examined the factor structure and reliability of the Chinese version of the SAS-2. Next, we conducted correlation and regression analyses to investigate the convergent and discriminant properties of SAS-2 in relation to other concepts, specifically the State–Trait Anxiety (Spielberger et al., 1971) and Athlete Burnout (Raedeke and Smith, 2001), referencing insights from previous studies (Shou et al., 2017; Wang et al., 2018). Lastly, we explored measurement invariance across genders and score differences in the Chinese version of the SAS-2.

Method

Participants

In Study 2, participants completed the survey on Tencent Questionnaire (https://wj.qq.com/), an online platform like Amazon Mechanical Turk, using their mobile phones. A total of 951 university athlete-students volunteered to participate in Study 2. These participants took this survey on the course for course credit. The protocol for the current study was approved by local Ethics Committee. To ensure data quality, this study sequentially set up two quality check questions in this survey. A total of 92 data were removed based on the results of the two quality testing entries. Moreover, in order to further ensure that participants took their answers seriously, we implemented a criterion based on participants' response time. As a result, we excluded 24 participants whose response time was less than 200 s, ultimately including 835 athlete-students for analysis.

Measures

SAS-2

The Chinese version of the SAS-2, developed in Study 1, was utilized in the study. The scale comprises three factors, namely somatic anxiety, worry, and concentration disruption, each consisting of five items. Participants were asked to rate 15 items on a four-point Likert scale, with 1 indicating 'not at all' and 4 indicating 'very much' (e.g., "My stomach feels upset"). Scores for each subscale were determined by averaging the scores of each item within the subscale. The resulting scores ranged from 1 to 4, with lower scores indicating a lower level of competitive anxiety in that specific dimension, while higher scores indicated a higher level of competitive anxiety in that dimension.

TABLE 2 Measurement invariance of the Chinese SAS-2 across language.

Model	χ^2	df	$\triangle\chi^2$	$\triangle$df	CFI	TLI	RMSEA	$\triangle$CFI	$\triangle$TLI	$\triangle$RMSEA
Baseline model	295.08	158			0.948	0.930	0.098			
Metric invariance	310.62	173	15.54	15	0.947	0.936	0.093	0.001	0.006	0.005
Scalar invariance	317.66	185	22.57	27	0.949	0.939	0.089	0.001	0.004	0.004

Baseline model = no invariance; Metric invariance = invariant factor loadings; Scalar invariance = invariant factor loadings and invariant item thresholds.

Athlete Burnout Questionnaire [ABQ]

The ABQ is a multidimensional instrument developed by Raedeke and Smith (2001) to measure athlete perceptions of burnout symptoms. It consists of a total of 15 items that assess three dimensions: Reduced sense of accomplishment, Emotional/physical exhaustion, and Sport devaluation. Participants provided responses to each item using a five-point Likert scale (e.g., "I'm accomplishing many worthwhile things in [sport]"), where 1 corresponded to "almost never," 2 to "rarely," 3 to "sometimes," 4 to "frequently," and 5 to "almost always." For each subscale, the dimension score was determined by calculating the mean of the five items within that subscale. Additionally, the total burnout score was calculated by obtaining the mean of all 15 items, incorporating responses from each dimension. The scale has found extensive usage in assessing burnout among youth and college athletes across different countries (Raedeke and Smith, 2001; Sharp et al., 2010). Its Chinese version has also demonstrated satisfactory levels of internal consistency reliability and convergent validity (Liu et al., 2022).

State trait anxiety inventory [STAI]

The STAI (Spielberger et al., 1971) was utilized in this study to assess participants' anxiety symptoms. The scale comprises 40 items that are divided into two subscales: state anxiety (items 1–20) and trait anxiety (items 21–40). Participants rated each item on a scale ranging from 1 to 4(e.g., "I feel calm"), with 1 indicating 'not at all' and 4 indicating 'very much.' Scores for each item were accumulated after converting the reverse scoring, with higher scores reflecting higher levels of state or trait anxiety. This scale has been validated in a Chinese sample, demonstrating good reliability (Shek, 1993).

Data analysis

Study 2 utilized the "lavaan" package (version 0.6-15) in R (version 4.3.0) for conducting CFA, as well as for conducting multigroup confirmatory factor analyses to test measurement invariance (Rosseel, 2012). Additionally, the "lavaanplot" package (Lishinski, 2018) was used to generate the path diagram of the SAS-2. Referring to the original study by Smith et al. (2006), we used the maximum likelihood estimator for the confirmatory factor analyses. Multiple fit indices were assessed, RMSEA, TLI, and CFI. According to Hu and Bentler (1999), an RMSEA value of ≤0.08 indicated an acceptable model fit, while a value of ≤0.05 indicated a good model fit. Additionally, a CFI or TLI value of ≥0.90 indicated adequate model fit. Starting from the perspective of exploring the convergent validity of the SAS-2 with other variables, we conducted a mediation analysis using the PROCESS procedure in SPSS, where the independent variables were STAI, the mediator variable was the SAS-2, and the dependent variable was the ABQ. Descriptive data analysis, reliability analysis, correlation analysis, and regression analysis were performed using IBM SPSS Statistics version 22.0 (IBM Corp., United States).

TABLE 3 Descriptive statistics and internal consistency of all measures used in the current study.

Scale	Mean	SD	Alpha	*N* of items
Somatic anxiety	9.07	3.03	0.86	5
Worry	10.55	3.42	0.91	5
Concentration Disruption	8.55	2.91	0.85	5
SAS-2	28.17	8.53	0.94	15
ABQ_RA	14.82	2.93	0.62	5
ABQ_E	13.40	4.13	0.90	5
ABQ_D	13.53	3.95	0.86	5
ABQ	41.76	10.17	0.92	15
STAI-S	45.56	7.28	0.89	20
STAI-T	44.03	8.81	0.81	20

SAS-2, Sport Anxiety Scale-2; ABQ_RA, Athlete Burnout Questionnaire: Reduced sense of accomplishment; ABQ_E, Athlete Burnout Questionnaire: Emotional/physical exhaustion; ABQ_D, Athlete Burnout Questionnaire: Sport devaluation; ABQ, Athlete Burnout Questionnaire; STAI-S, State trait anxiety inventory-state anxiety; STAI-T, State trait anxiety inventory-trait anxiety.

Results

Descriptive statistics

Descriptive statistics and internal consistency estimate for all measures are presented in Table 3. The Cronbach's alpha coefficients for all three factors of the SAS-2, as well as the total SAS-2 score, were found to be greater than 0.80. Additionally, all other subscales of the variables of interest demonstrated good reliability coefficients, with the lowest coefficient observed for the Reduced sense of accomplishment subscale in the ABQ (0.62), and the highest coefficient recorded for the ABQ total scale (0.92). Furthermore, we computed the Average Variance Extracted (AVE) and Composite Reliability (CR) for the three SAS-2 factors. The results indicated that for Somatic anxiety, AVE was 0.70, and CR was 0.83. For Worry, AVE was 0.79, and CR was 0.89. Lastly, for Concentration Disruption, AVE was 0.65, and CR was 0.78.

Confirmatory factor analysis

The results revealed that the model fit indices for the model were adequate (χ^2=403.06, df = 61, p < 0.001), and the CFI (0.96) and TLI (0.93) results were both above 0.90, indicating that this model provided a satisfactory fit. The RMSEA (0.08), although not meeting the criteria for a good fit, is still considered acceptable. Figure 1

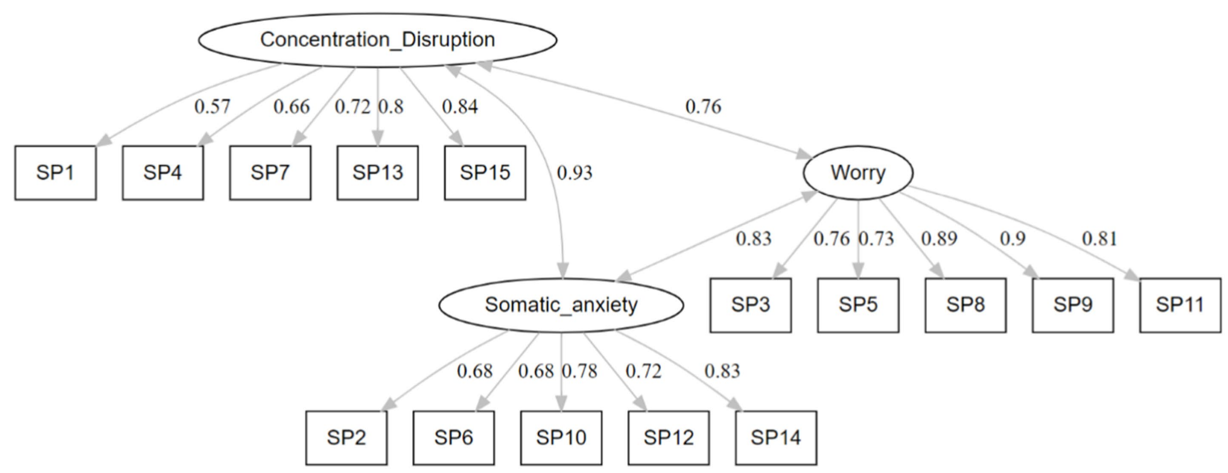

FIGURE 1
Path diagram of the SAS-2.

demonstrates that all items displayed satisfactory factor loadings, which were equal to or greater than 0.40. Additionally, moderate to strong correlations were observed between the three factors, with values ranging from 0.76 to 0.93.

Invariance of the SAS-2 across genders

In our study, we assessed the measurement invariance of the Chinese version of the SAS-2 across genders. To achieve this, we first established configural invariance across genders, ensuring that the underlying structure of the scale remained consistent. Subsequently, we conducted tests to examine measurement invariance at both the metric and scalar levels. As shown in Table 4, the changes in CFI, TLI, and RMSEA were all less than 0.01 in both the metric invariance model and the scalar invariance model results (Cheung and Rensvold, 2002). Therefore, these findings provide strong support for the presence of metric and scalar invariance across genders.

Convergent and discriminant validity

We first analyzed the relationships between the three factors of the SAS-2 and found significant correlations between each pair of factors (Table 5). The correlation coefficients between Somatic Anxiety and Worry were 0.75 ($p < 0.001$), and between Somatic Anxiety and Concentration Disruption were 0.79 ($p < 0.001$). Furthermore, the correlation coefficient between Worry and Concentration Disruption was 0.69 ($p < 0.001$). Subsequently, correlation analyses were conducted to examine the relationships between the factors of the SAS-2 and the criterion scales representing externally related concepts. The results of the correlation analysis are presented in Table 5. The results indicated that all three factors of the SAS-2, namely Somatic anxiety, Worry, and Concentration Disruption, were significantly and positively correlated with all three factors of the ABQ, as well as with State–Trait Anxiety. Notably, all three factors of the SAS-2 had the highest correlations with emotional/physical exhaustion among these external criteria.

Multiple regression analyses were conducted with the three factors of the SAS-2 as independent variables and the remaining association criteria as dependent variables to assess the unique contribution of each SAS-2 factor in predicting each association criterion (Table 6). Concentration Disruption was found to significant and uniquely predict reduced sense of accomplishment in the ABQ. Both Somatic Anxiety and Concentration Disruption significantly predicted Emotional/Physical Exhaustion and Sport Devaluation, respectively, with Concentration Disruption demonstrating the strongest contribution. Finally, Concentration Disruption was found to uniquely predict state and trait anxiety.

The mediation analysis

To further scrutinize the convergent validity of the Chinese version of the SAS-2 concerning STAI and ABQ, we performed a series of mediation analyses. In these analyses, we utilized STAI as the independent variable, SAS-2 as the mediator, ABQ as the dependent variable, and included gender as a covariate. The findings indicate that among the three SAS-2 factors, only Concentration Disruption acted as a partial mediator in the relationship between trait anxiety and athlete burnout. Conversely, in the case of the relationship between state anxiety and athletic burnout, both Concentration Disruption and Somatic Anxiety served as partial mediators. This outcome mirrors the regression results presented in Table 6, providing additional support for the association between Concentration Disruption, athlete burnout, and both state and trait anxiety (Figure 2).

Differential analysis of gender on the SAS-2

We also compared the differences in the SAS-2 among participants of different genders. Table 7 displays the results of descriptive data and independent samples t-tests.

It was found that female college athletes scored significantly higher on Somatic anxiety ($t = -2.21$, $df = 833$, $p < 0.05$) and Worry ($t = -3.17$, $df = 833$, $p < 0.01$) than male college athletes. The difference in scores on Concentration Disruption between college athletes of different genders was not significant. Lastly, female student-athletes also scored higher than male student-athletes on the SAS-2 total score ($t = -2.18$, $df = 833$, $p < 0.05$).

TABLE 4 Measurement invariance of the Chinese SAS-2 across gender.

Model	χ^2	df	$\Delta\chi^2$	Δdf	CFI	TLI	RMSEA	ΔCFI	ΔTLI	ΔRMSEA
Baseline model	659.23	148			0.943	0.919	0.091			
Metric invariance	659.18	166	35.96**	18	0.941	0.926	0.087	0.002	0.007	0.004
Scalar invariance	720.01	178	60.78***	30	0.940	0.929	0.085	0.001	0.003	0.002

Baseline mode = no invariance; Metric invariance = invariant factor loadings; Scalar invariance = invariant factor loadings and invariant item thresholds. **$p < 0.01$; ***$p < 0.001$.

TABLE 5 Correlations results between SAS-2 and criterion variables.

Scale	Somatic anxiety	Worry	Concentration disruption
Somatic anxiety	–		
Worry	0.75**	–	
Concentration disruption	0.79**	0.69**	–
ABQ_RA	0.28**	0.23**	0.32**
ABQ_E	0.39**	0.31**	0.45**
ABQ_D	0.36**	0.27**	0.41**
ABQ	0.38**	0.28**	0.36**
STAI-S	0.32**	0.28**	0.36**
STAI-T	0.31**	0.28**	0.37**

ABQ, Athlete Burnout Questionnaire; ABQ_RA, Athlete Burnout Questionnaire: Reduced sense of accomplishment; ABQ_E, Athlete Burnout Questionnaire: Emotional/physical exhaustion; ABQ_D, Athlete Burnout Questionnaire: Sport devaluation; ABQ, Athlete Burnout Questionnaire; STAI-S=State trait anxiety inventory-state anxiety; STAI-T, State trait anxiety inventory-trait anxiety. *$p < 0.05$. **$p < 0.01$.

TABLE 6 Summary of regression analyses showing the unique association of each SAS-2 factors (Beta coefficients) with the criterion variables.

Scale	Somatic anxiety	Worry	Concentration disruption
ABQ_RA	0.07	−0.01	0.27***
ABQ_E	0.13*	−0.05	0.39***
ABQ_D	0.14*	−0.08	0.35***
ABQ	0.13*	−0.05	0.37***
STAI-S	0.05	0.04	0.30***
STAI-T	0.09	0.01	0.29***

*$p < 0.05$. ***$p < 0.001$.

Discussion

The current study aimed to translate the SAS-2 into a bilingual sample and conduct cross-validation in a sample of college athletes. In Study 1, we developed the Chinese version of the SAS-2. The bilingual validation results indicate that the meaning of the Chinese version of SAS-2 aligns consistently with the English version of SAS-2, and measurement invariance exists in the English and Chinese versions. In Study 2, we assessed the factor structure of the Chinese version of the SAS-2 and examined its convergent and divergent relationships with other conceptually related criteria. The findings indicated that the Chinese version of the SAS-2 successfully replicated the original three-factor model with good construct validity. Additionally, the regression results highlighted the unique contribution of the SAS-2 factors in predicting other relevant conceptual criteria. Moreover, measurement invariance was observed for the SAS-2 across gender. Lastly, female student-athletes exhibited significantly higher scores than their male counterparts on the SAS-2 Somatic Anxiety and Worry subscales.

More specifically, the Chinese SAS-2 scales also exhibited adequate to good internal consistency. The total scores of the SAS-2 had high reliability (α=0.94), like previous studies conducted with English-speaking samples [α=0.91; Smith et al. (2006)] and Brazilian samples (α=0.88; Silva-Rocha et al. (2019)). Consistent with the original study (Smith et al., 2006), the confirmatory factor analyses also supported the three-factor model of the Chinese version of the SAS-2, with factor loadings ranging between 0.57 and 0.90 for all items. The results of the model fit, on the other hand, indicated that the model fit of the data was generally acceptable (CFI = 0.96, TLI = 0.934, RMSEA = 0.082), as recommended by Bentler and Bonett (1980). When the TLI is greater than 0.90, it indicates an acceptable fit, and when both the CFI and TLI are greater than 0.95, it suggests that the model fit to the data is generally good overall (Hu and Bentler, 1999). Although the current study resulted in RMSEA values around 0.080, previous studies have concluded that RMSEA values between 0.05 and 0.08 are considered acceptable, while values between 0.08 and 0.1 are considered marginal (Fabrigar et al., 1999). Hence, these findings imply that the Chinese version of the SAS-2 not only exhibits strong reliability but also demonstrates sound construct validity, making it a valuable tool for application among Chinese student-athletes.

The present study also examined the convergent and discriminant validity of the SAS-2. Convergent validity was established by demonstrating significant correlations between the SAS-2 and other conceptually relevant scales. Correlation analyses revealed significant correlations between somatic anxiety on the SAS-2 and all three subscales of the ABQ, in addition to state and trait anxiety (ranging from 0.28 to 0.39). Similarly, worry exhibited significant correlations with all three ABQ subscales as well as state and trait anxiety (ranging from 0.23 to 0.31). Importantly, Concentration Disruption demonstrated the highest coefficients among these correlated variables, ranging from 0.32 to 0.45. This finding aligns with prior research (Raedeke and Smith, 2001; Liu et al., 2022). For instance, in Liu et al. (2022) study, it was observed that all three factors of the ABQ exhibited significant positive correlations with both worry and Concentration Disruption. Notably, Concentration Disruption displayed the highest correlation with all three factors of the ABQ. Finally, consistent with previous findings, we found that the three factors of the SAS-2 were significantly correlated with trait and state anxiety (Smith et al., 1995; Liu et al., 2022). Thus, the SAS-2 exhibits a shared variance with the general anxiety measure, indicating a degree of commonality between the two constructs.

The SAS-2 scales also evidenced discriminant validity. Regression analyses found that somatic anxiety significantly predicted emotional/physical exhaustion and sport devaluation of the ABQ, but not Reduced Sense of Accomplishment. Furthermore, somatic anxiety did not significantly predict state and trait anxiety. Worry, on the other hand, failed to significantly predict either the three factors of

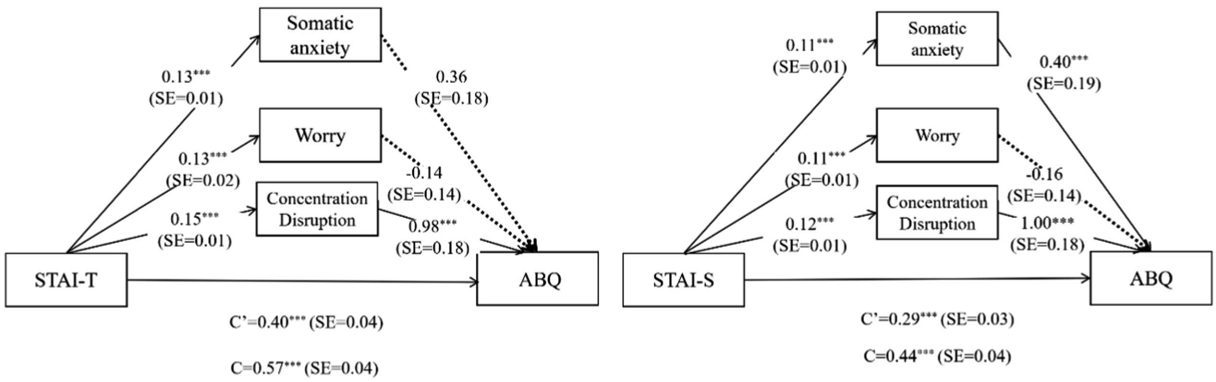

FIGURE 2
Results of the mediation effects analysis. ***$p < 0.001$; c' = direct effect; c = Total effect. The dotted line indicates that the path effect is not significant.

TABLE 7 Independent samples *t*-test results (M ± SD) on the SAS-2 between participants of different genders.

Variables	Male		Female		*t*	*p*
	Mean	SD	Mean	SD		
Somatic anxiety	8.88	3.00	9.35	3.06	−2.21*	0.028
Worry	10.24	3.42	11.00	3.38	−3.17**	0.002
Concentration disruption	8.52	2.98	8.60	2.82	−0.38	0.707
SAS-2	27.64	8.65	28.95	8.30	−2.18*	0.030

*$p < 0.05$. **$p < 0.01$.

the ABQ or state and trait anxiety. Finally, we found that concentration disruption significantly predicted all three factors of the ABQ, as well as state and trait anxiety. Concentration disruption alone explained a significant amount of variance in the reduced sense of accomplishment and state and trait anxiety. Additionally, concentration disruption was also the strongest predictor of the emotional/physical exhaustion and sport devaluation variables of the ABQ. In summary, our findings contribute to a deeper understanding of the interplay between the Chinese version of the SAS-2 and these associated measures, offering fresh insights into the convergent and discriminant validity of the SAS-2 in cross-cultural settings.

Additionally, we explored differences in measurement invariance and scores on the three factors of the SAS-2 among college athletes of varying genders. The findings revealed that there was measurement invariance in the Chinese version of the SAS-2 across genders. Furthermore, female college athletes scored significantly higher than their male counterparts on measures of somatic anxiety and worry. This finding is consistent with previous research (Ramis et al., 2015; Correia and Rosado, 2019; Rice et al., 2019). For example, a previous study of a sample of athletes from three different countries also found that females scored significantly higher on worry than males (Ramis et al., 2015). Rice et al. (2019) conducted a systematic regression and meta-analysis of the existing literature and then found that female athletes had higher rates of anxiety and depression than male athletes. Considering the relationship between sport anxiety and well-being and performance, coaches should target female athletes to provide appropriate measures to reduce their sport anxiety levels.

Limitations and future directions

This study exhibits certain limitations. Firstly, our sample consisted of college students in sports, and we did not examine the psychometric properties of the SAS-2 in a younger adolescent sample. Therefore, future research could focus on examining the reliability and validity of the Chinese version of the SAS-2 in younger samples. Additionally, the current study did not measure participants' well-being and athletic performance to explore the relationship between the SAS-2 and college athletes' overall well-being and performance. Consequently, further research could delve into the association between sports anxiety, mental health, and related variables in college athletes using the SAS-2. In addition to the SAS-2, future studies could incorporate objective physiological measures such as galvanic skin response and blood lactate levels to collect comprehensive psychological and physiological data on athletes. For instance, previous research has indicated that elevated blood lactate levels are linked to decreased attention and working memory (Coco et al., 2020). This combined dataset could serve as a valuable resource for enhancing athletic performance, leveraging biofeedback training in conjunction with psychophysiological responses (Pusenjak et al., 2015).

In summary, the present findings indicate that the Chinese version of the SAS-2 exhibits a sound factor structure and reliable internal consistency, as well as measurement invariance across languages and genders. Furthermore, our results provide support for the convergent and discriminant validity of the SAS-2, as evidenced by its associations with various anxiety descriptors and athlete burnout measures in a sample of Chinese student-athletes.

Data availability statement

The original contributions presented in the study are included in the article/supplementary materials, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by the local Ethics Committee (School of General Education, Chongqing Institute of

Engineering). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

JZ: Conceptualization, Data curation, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. ZZ: Conceptualization, Data curation, Formal analysis, Supervision, Writing – original draft, Writing – review & editing. SP: Supervision, Writing – review & editing. AV: Supervision, Writing – review & editing. RB: Supervision, Writing – review & editing. WT: Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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A new EEG neurofeedback training approach in sports: the effects function-specific instruction of Mu rhythm and visuomotor skill performance

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Introduction: Achieving optimal visuomotor performance in precision sports relies on maintaining an optimal psychological state during motor preparation. To uncover the optimal psychological state, extensive EEG studies have established a link between the Mu rhythm (8–13 Hz at Cz) and cognitive resource allocation during visuomotor tasks (i.e., golf or shooting). In addition, the new approach in EEG neurofeedback training (NFT), called the function-specific instruction (FSI) approach, for sports involves providing function-directed verbal instructions to assist individuals to control specific EEG parameters and align them with targeted brain activity features. While this approach was initially hypothesized to aid individuals in attaining a particular mental state during NFT, the impact of EEG-NFT involving Mu rhythm on visuomotor performance, especially when contrasting the traditional instruction (TI) approach with the FSI approach, underscores the necessity for additional exploration. Hence, the objective of this study is to investigate the impact of the FSI approach on modulating Mu rhythm through EEG-NFT in the context of visuomotor performance.

Methods: Thirty novice participants were recruited and divided into three groups: function-specific instruction (FSI, four females, six males; mean age = 27.00 ± 7.13), traditional instruction (TI, five females, five males; mean age = 27.00 ± 3.88), and sham control (SC, five females, five males; mean age = 27.80 ± 5.34). These groups engaged in a single-session EEG-NFT and performed golf putting tasks both before and after the EEG-NFT.

Results: The results showed that within the FSI group, single-session NFT with augmented Mu power led to a significant decrease in putting performance (p = 0.013). Furthermore, we noted a marginal significance indicating a slight increase in Mu power and a reduction in the subjective sensation of action control following EEG-NFT (p = 0.119). While there was a positive correlation between Mu power and mean radial error in golf putting performance (p = 0.043), it is important to interpret this relationship cautiously in the context of reduced accuracy in golf putting.

Discussion: The findings emphasize the necessity for extended investigation to attain a more profound comprehension of the nuanced significance of Mu power in visuomotor performance. The study highlights the potential effectiveness of the FSI approach in EEG-NFT and in enhancing visuomotor performance, but it also emphasizes the potential impact of skill level and attentional control, particularly in complex visuomotor tasks.

KEYWORDS

complex visuomotor skills, simple visuomotor skills, Mu rhythm, alpha rhythm, mental training, golf putting

Introduction

Optimizing visuomotor performance requires individuals to achieve and maintain an optimal psychological state during motor preparation (Krane and Williams, 2006). In visuomotor tasks, such as golf putting and shooting, motor programming is a crucial psychological construct that involves organizing and controlling the various degrees of freedom in movement to execute a skill (Schmidt et al., 2018). Successful motor programming leads to superior visuomotor performance by allowing individuals to execute appropriate motor control, such as movement force, direction, and stability (Cooke et al., 2014; Wang et al., 2019, 2022; Chen et al., 2022a). The regulation of motor programming processes during skill execution significantly impacts visuomotor performance, making it essential to identify innovative approaches to refine these processes (Cooke et al., 2015; Bertollo et al., 2016; Chang and Hung, 2020).

Prior research utilizing electroencephalograms (EEG) has established a link between motor programming and motor performance. Specifically, the Mu rhythm, identified within the 8–13 Hz frequency range in the central brain region (Cooke et al., 2014, 2015), is significant in the context of motor programming. This rhythm is indicative of the allocation of cognitive resources during both the observation and execution phases of goal-directed actions (Pineda, 2005; Cannon et al., 2014; Cooke et al., 2015). It serves as a neural marker for understanding the association between motor programming processes and motor preparation for motor actions, emphasizing its role in both the planning and implementation stages of movement. Mu rhythm activity has been found to influence visuomotor performance during golf putting (Babiloni et al., 2008; Cooke et al., 2014; Wang et al., 2019, 2020, 2022) and shooting (Haufler et al., 2000; Del Percio et al., 2009; Bertollo et al., 2016) in the field of sport psychophysiology. However, the physiological function of the Mu rhythm during visuomotor actions remains a topic of ongoing scientific debate. Specifically, Kerick et al. (2004) have found that increased Mu power in the central region leads to improved shooting performance, indicating deactivation of the central area, which may be associated with adaptive sensorimotor integration and less cognitive effort due to automaticity (Kober et al., 2015; Cheng et al., 2017). That is, increased Mu power may reflect less allocation of irrelevant cognitive resources to response motor programming for psychomotor efficiency and to exemplify a refinement of neural processes, consistent with the stage of automaticity (Cheng et al., 2015b; di Fronso et al., 2016; Hatfield, 2018). However, these findings contrast with other studies that have reported an opposite relationship between Mu rhythm and motor performance. For instance, recent research has suggested that decreased Mu power is associated with superior performance in a golf task (Cooke et al., 2014; Wang et al., 2019, 2020), suggesting higher cognitive resources to response motor programming, leading to adaptive motor control and increased action control levels during golf tasks (Wang et al., 2023). Given these conflicting results in the visuomotor tasks (i.e., shooting and golf), further investigation is needed to clarify the role of Mu rhythm in visuomotor tasks, which may offer a more precise understanding of the physiological function of motor programming in visuomotor performance.

Recent studies have been using EEG neurofeedback training (NFT) to clarify the role of EEG activity (Kao et al., 2014; Cheng et al., 2015a; Ring et al., 2015; Chen et al., 2022b; Wang et al., 2023). EEG-NFT is a tool to indirectly affect brain function and link brain with psychological states for sports performance (Cooke et al., 2018; Cheng and Hung, 2020a; Onagawa et al., 2023). For example, a decrease in frontal midline theta (FMT; 4–7 Hz) power that is linked to sustained attention (Kao et al., 2014) can improve putting performance in skilled golfers (Chen et al., 2022b). In addition, increased sensorimotor rhythm (SMR; 12–15 Hz) power that is associated with attentional processing can improve putting performance in skilled golfers (Cheng et al., 2015a; Afrash et al., 2023) and novice golfers (Pourbehbahani et al., 2023). In addition to FMT and SMR, Mu rhythm can also modulate visuomotor performance. Wang et al. (2023) conducted a first randomized controlled trial study to explore the influence of Mu rhythm modulation on visuomotor performance. They recruited 30 novice golfers divided into three groups: increased Mu rhythm, decreased Mu rhythm, and sham control and performed a golf putting task. The findings indicated that reduction in Mu power in the decreased Mu rhythm group resulted in increased subjective sensation of action control level and improved performance. However, this finding is inconsistent with Kerick et al. (2004), who reported that an increase in Mu power can cause performance improvement in shooting task. Wang et al. (2023) highlighted that the complexity of motor skills may influence the Mu power and visuomotor performance. This observation aligns with Berka et al. (2010) distinction between complex visuomotor skills and simple visuomotor skills, such as golf and shooting. Compared to simple skills, complex skills require more cognitive resources and involve intricate neural processes to achieve superior performance (Cooke et al., 2015; Afrash et al., 2023). As a result, a decrease in Mu power may have a positive impact on performance in complex visuomotor task (Afrash et al., 2023; Wang et al., 2023). Nevertheless, Wang et al. (2023) suggested that the association between Mu rhythm and performance is still ambiguous in the visuomotor task because no significant changes in Mu power were observed in the increased Mu rhythm group. The failed Mu power manipulation in the increased Mu rhythm group may be because of a lack of specific verbal instructions for individuals to learn how to increase Mu power during EEG-NFT (Chen et al., 2022b). Therefore, it is important to use specific instructions for EEG-NFT execution to better understand the physiological function of Mu rhythm in visuomotor performance.

To address the need for specific instructions in EEG-NFT, the utilization of the function-specific instruction (FSI) approach in EEG-NFT for sports has been explored in a study that conducted by Chen et al. (2022b). FSI approach can be used to address the inconsistent findings in previous studies (Kerick et al., 2004; Wang et al., 2023). This approach provides function-directed verbal instructions for participants to control specific EEG parameters, aiming to align the instructions with targeted brain activity features during EEG-NFT (deCharms et al., 2005; Chen et al., 2022b). Specifically, the FSI approach considers the meaning of the brainwave function in the target region and the EEG power magnitude to attain a specific mental state. A previous study has provided evidence of the positive effects of the

FSI approach in EEG-NFT for sport performance improvement (Chen et al., 2022b; Wu et al., 2023). For instance, Chen et al. (2022b) recruited 36 skilled golfers, which were divided into three groups: FSI, traditional instruction (TI), and sham control (SC), and measured their putting performance before and after performing EEG-NFT. The FSI group demonstrated a significant improvement in putting performance and decrease in FMT power. These findings suggest that the FSI approach is more effective than TI approach in manipulating EEG activity, enhancing sustained attention and putting performance in skilled golfers (Chen et al., 2022b). However, despite these findings, little is known about the effects of Mu activity with the FSI approach in EEG-NFT. Mu activity has been demonstrated to function as an indicator of cognitive resource allocation through conscious effort during preparation, consequently influencing motor performance (Cooke et al., 2015; Wang et al., 2023). By incorporating the FSI approach, Mu NFT can potentially alter visuomotor performance. Therefore, adopting the FSI approach in Mu NFT can provide insights into targeted interventions for enhancing visuomotor performance in sports and other motor skills.

The objective of the current study is to examine if implementing the FSI approach can improve the efficacy of Mu NFT and its effect on visuomotor performance. To do this, we replicate the study that conducted by Wang et al. (2023) who recruited novice golfers and adopted single-session EEG-NFT to examine Mu activity impact on complex visuomotor performance, especially golf putting performance (Kao et al., 2014; Chen et al., 2022a). Although multi-session interventions in EEG-NFT may increase the effectiveness of learning outcomes, such as three (Arns et al., 2008), six (Afrash et al., 2023), and eight (Cheng et al., 2015a) sessions, a single-session intervention in EEG-NFT with an FSI approach has been found to be sufficient for individuals to learn to control neural activity in the brain (Kao et al., 2014; Chen et al., 2022b; Wu et al., 2023). In addition, a single-session intervention in EEG-NFT provides a possibility for practical application in sports (Hung and Cheng, 2018; Cheng and Hung, 2020b; Wang et al., 2023). Accordingly, the study aims to complement the findings of Wang et al. (2023) by manipulating Mu rhythm during a golf putting task in a single-session EEG-NFT and examining whether increased Mu power (i.e., a decrease in cortical activity), which is likely associated with reduced cognitive effort (Kerick et al., 2004), could result in improved or decreased performance in a golf putting task. To test our hypothesis, we established three groups following the previous protocol (Chen et al., 2022b): an FSI group, a TI group, and a SC group. We hypothesize that the FSI group could exhibit a more significant alteration in performance in a golf putting task (i.e., a complex visuomotor task) than the TI and SC groups after a single-session Mu NFT. Additionally, we hypothesize that the FSI group will exhibit significantly increased Mu power after a single-session Mu NFT than the other groups.

Materials and methods

Participants

A power analysis was conducted to determine the minimum detectable effect for a repeated measure, within-between interaction, multivariate analysis of variance (MANOVA) sample size calculation using G*Power, in accordance with the guidelines established by Faul et al. (2007). The study utilized values of $\alpha = 0.05$, power = 0.80, effect size = 0.70 (corresponding to $\eta_p{}^2 = 0.33$), with three groups (TI, FSI, and SC) and eight measurements (pre-post measurements × electrode sites) in a priori type of power analysis, following the research design employed by Wang et al. (2023). We chose Wilks U in the approximation (F-transformation; Rao, 1951) and O'Brien and Shieh (1999), recommended. The minimum sample size required was determined to be $N = 26$. To mitigate potential biases arising from power analysis, which has been highlighted in the neuroscience field (Albers and Lakens, 2018; Algermissen and Mehler, 2018), a total of 30 novices were recruited in three groups. All participants were assigned to the TI (five females, five males; mean age = 27.00 ± 3.88), FSI four females, six males; mean age = 27.00 ± 7.13), and S (five females, five males; mean age = 27.80 ± 5.34), respectively. All eligible participants were screened based on the following criteria: (1) no history of psychiatric or neurological disease; (2) right-handed; (3) not taking medication affecting the central nervous system or brain; (4) normal or corrected-to-normal vision; and (5) normal visual attention that was assessed by using Trail Making Test A (Lezak et al., 2004). Informed consent was obtained from all participants before the study commenced. This study was approved by the institutional review board of Bielefeld University, and all procedures and methods were conducted in accordance with the relevant ethical guidelines and regulations.

Measures

Golf putting task

The participants employed a standard putter suitable for regular-sized golf balls (diameter = 4.27 cm) to execute putts aimed toward a target positioned 3 meters away from them on an artificial putting green (4 × 9 m). Both before and after the EEG-NFT intervention, the participants performed 20 putts (i.e., pretest-posttest). During the putting task, the definition of the motor preparation period was that specified by Wang et al. (2020), who defined it as the period between placing the putter behind the ball and initiating the backswing. For each trial, backswing movement was detected by an infrared sensor as an event marker (Figure 1).

Subjective stress level

To address the potential influence of stress on the experimental outcomes (confounding effects), a subjective evaluation of stress levels was conducted using an 11-point Likert scale ranging from 0 (representing no stress) to 11 (indicating the highest level of stress), as previously described by Wang et al. (2023). This assessment was carried out during the golf putting task both before and after EEG-NFT.

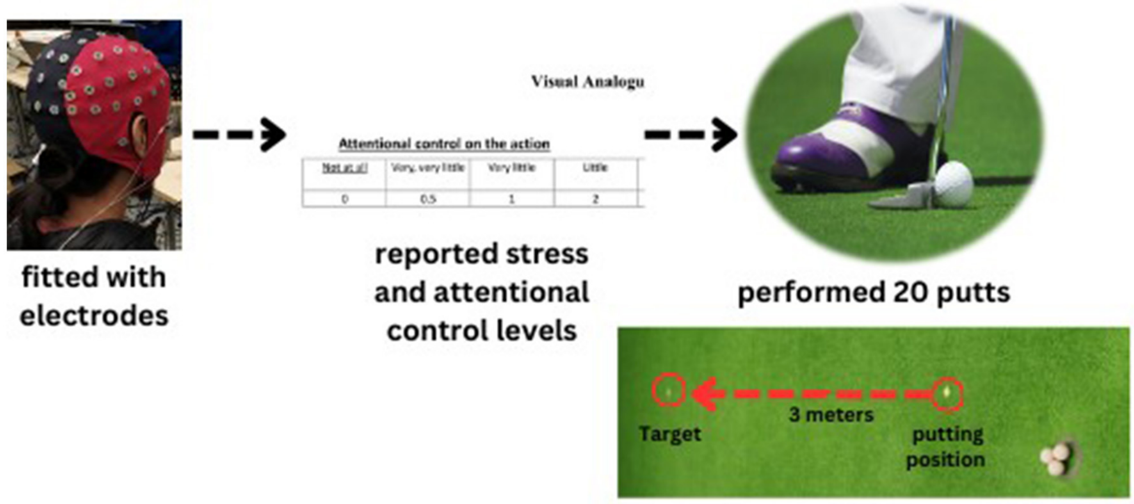

FIGURE 1
The golf putting task and procedure.

Subjective psychological state (attentional control level)

Research suggests that the 8–13 Hz frequency range at the central cortex (Cz) is associated with both motor programming in neuromotor process and attentional control of actions (Wang et al., 2023). To assess participants' attentional control during the golf putting task, they were asked to rate their sensation of action control level on an 11-point Likert scale ranging from 0 (not at all) to 11 (maximum possible; Wang et al., 2022) before and after EEG-NFT intervention. Specifically, we asked participants to report the number on the 11-point Likert scale before proceeding to perform 20 putts. Additionally, they reported the number when standing on the putting area in both the pre and posttests separately.

Instrumentation

Vicon motion systems

A motion capture system (Vicon Motion Systems, Oxford, UK) was utilized to record putting performance. Specifically, the ball's movement was monitored using six T10 charge-coupled device cameras with a spatial resolution of ∼0.25 mm and a temporal resolution of 200 Hz, recording its rolling and stopping.

EEG

In accordance with the international 10-10 system, 64 electrode sites were utilized to record data. Electrodes were placed on the left and right ear mastoids (M1, M2) to serve as the electrical reference and at the anterior frontal zone position (AFz; Jurcak et al., 2007) to serve as the ground electrode. In addition, bipolar configurations were placed superior and inferior to the left eye, and on the left and right orbital canthi to record vertical and horizontal electrooculograms (HEOL, HEOR, VEOU, and VEOL). The eego system (ANT Neuro, Germany) was used with a bandpass filter from 1 to 100 Hz and a 50 Hz Notch filter. Data were collected using the eego software with a sampling frequency of 500 Hz, while maintaining electrode impedance below 10 kΩ. The Mu rhythm was extracted at Cz in the 8–13 Hz frequency range (Wang et al., 2019, 2020).

Neurofeedback recording

Neurofeedback training was conducted using the BioTrace+ software (MindMedia, NeXus-10, the Netherlands), with signals acquired using a DC-coupled EEG amplifier featuring a 24-bit A/D converter to extract Mu rhythm. The amplitude of Mu rhythm was then converted into an audio-feedback tone using acoustic bass.

Procedures

We used a stratified random control experimental design by gender to divide the population into three subgroups (TI, FSI, and SC). We followed our previous study's design as a pretest-posttest design for a single training session (Kao et al., 2014; Ros et al., 2014; Chen et al., 2022b; Wang et al., 2023). Our study incorporated three groups as a between-subject factor and employed a pre-posttest measurement as a within-subject factor. We instructed the participants to avoid consuming any food or drinks that contain alcohol or caffeine for 24 h before the day of the test. On the day of the experiment, we (a) explained the nature of the study and (b) asked the participants to sign an informed consent form. Next, we instructed them to (c) put on the Lycra electrode cap and (d) watch a 15-s putting video without any golf instruction. After that, we asked them to (e) perform a warm-up using ten balls, with the goal of putting the golf ball as accurately as possible. Then, we asked them to (f) report their attentional control and stress levels before they proceeded to (g) perform 20 putts for the pretest. After the pretest, the participants underwent (h) the EEG-NFT intervention. Following the intervention, we asked them to (i) report their attentional control and stress levels once again before they proceeded to (j) perform another 20 putts for the posttest (Figure 1). The experiment lasted ∼2.5 h in total.

Neurofeedback training protocol

The present study followed our previous neurofeedback training protocol (Wang et al., 2023). Cortical activity was recorded from the Cz site on the EEG cap with the reference and ground electrodes attached to the left and right ear mastoids, respectively. Afterward, two training stages (i.e., pre-EEG-NFT, acquisition) were carried out. In the pre-EEG-NFT stage, we (a) asked the participants to perform ten putts for warm up, (b) averaged Mu amplitude over the ten putts, which defined as the individual training criteria (training baseline) for each participant, (c) then calculated + 20% of the baseline as a training target for the TI group and FSI group (Chen et al., 2022b; Wang et al., 2023). The instruction given to TI group and FSI group was "the computer will play a tone (auditory feedback) and display the signals on a screen (visual feedback) that is linked to your brain activity. Visual feedback is visual output from a system, such as a computer game, that allows you to interact better with the system. Auditory feedback is auditory output from a system. When you reach a prescribed level of brain activity (Mu amplitude), the tone will turn on. It represents that you are in the state that we are training for, and you need to remember the feeling that you experience when you receive the feedback".

Importantly, two customized instructions were used in TI group and FSI group. In the TI group, the customized instruction was "Please develop your own strategies to control the brain wave". However, in the FSI group, we asked participants to focus on their core component action (e.g., the ball path, clubface, or shoulders), that is, the action highly associated with the golf-putting task (Wang et al., 2021) and then asked them to gradually decrease attentional control of actions as increase Mu power at Central region (Wang et al., 2023). Nonetheless, random feedback was conducted for the SC group in each training trial. To guarantee the randomized feedback, we randomly played the feedback tone using random.org.

To ensure that EEG-NFT learning could be achieved, the participants were required to meet a successful training ratio of 70% (Gruzelier, 2014) in a single training trial (40 s), which was defined as the amount of time that the participant successfully entered the training threshold during the motor preparation period. If participants did not achieve the training ratio of 70%, the Mu power baseline would be increased by 10% until the training ratio of 70% was achieved.

During the acquisition stage, we utilized two distinct conditions—sitting and standing—as recommended by Kao et al. (2014) to progressively simulate putting conditions for participants in groups TI and FSI (see Figure 2). To enhance the EEG-NFT efficacy, we gradually adjusted the training threshold by +10% in the sitting condition and +20% in the standing condition. To evaluate the level of control achieved by the participants over their EEG, a successful training ratio of 80% was established. In other words, a higher ratio would indicate that the participant had better control over their EEG. During the sitting condition, the participants were instructed to sit 60 cm away from a computer monitor. To deem the training successful, the average training ratio had to be above 80% for three consecutive trials, with a minimum of six blocks of audiovisual feedback provided to the participants. Once the participants achieved the successful training criteria in the sitting condition, they were permitted to proceed to the standing condition. During the standing condition, the participants were required to maintain their pre-putt posture while holding a putter. The visual feedback was removed during the standing condition to allow the participants to engage in a pre-putt routine similar to real-life. The training protocol was identical to that of the sitting condition, and the participant had to achieve an average successful training ratio >80% for three consecutive trials of at least six blocks before they could move on to the post-task assessments.

Data analysis

Behavioral data

To evaluate the performance outcomes, the researchers used a pre-posttest mean radial error (MRE) to measure putting accuracy, as described by our previous EEG-NFT study (Wang et al., 2023). MRE is defined as the average distance in millimeters that each subject's putt outcome deviated from the center of the target. A higher MRE indicates a larger average radial error, indicating lower accuracy and performance.

EEG data

The EEG data underwent preprocessing using both EEGLAB functions (Delorme and Makeig, 2004) and custom MATLAB scripts (MathWorks, U.S.A.). To preprocess the EEG data, the researchers performed the following steps: (1) re-referenced the data to the averaged mastoids (A1, A2); (2) applied a bandpass filter using a basic finite infinite response (FIR) filter, ranging from 1 Hz (low-pass) to 30 Hz (high-pass); (3) extracted epochs within a time window of −3,000 to 1,000 ms before the putting activity; and (4) removed channels with bad signal quality; (5) rejecting gross artifacts (amplitudes exceeding ± 100 μV) to eliminate any potential biological artifacts (e.g., muscle activation artifacts; Wang et al., 2020). As a result, a total of three trials were rejected during both the pretest and posttest stages, with the number of rejected trials varying across the groups: FSI group = three trials pretest and three trials posttest, TI group = 0 trials pretest and 0 trials posttest, and SC = 0 trials pretest and 0 trials posttest.; (6) running independent component analysis (ICA; Runica Infomax algorithm; Makeig et al., 1995) to identify and remove components caused by blinks, eye movements, and other non-neural activity; (7) interpolating channels with bad signals. The resulting clean signals were then divided into 2-s epochs spanning a time window of −2,000 to 0 ms before the putting activity. Finally, the power spectrum between 8 and 13 Hz was calculated using the Welch estimation method with a Hanning windowing function as described by Welch (1967). The pretest trial

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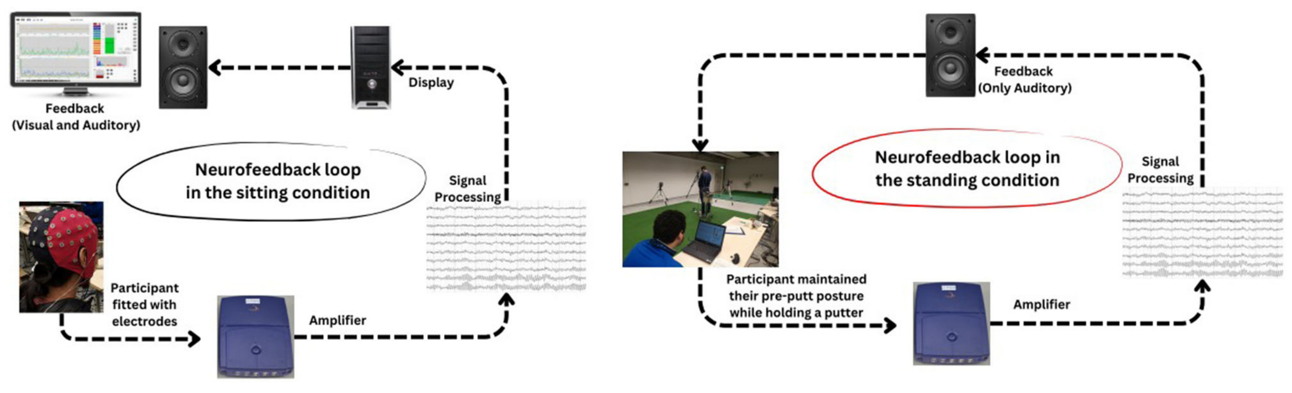

FIGURE 2
Flowcharts present neurofeedback training protocols in sitting and standing conditions.

counts for FSI, TI, and SC groups were 19.70 ± 0.67, 20.00, and 20.0 trials, respectively. Posttest trial counts were 19.70 ± 0.67, 20, and 20 trials, respectively. To ensure that differences in the number of trial counts between the groups did not influence the results, a one-way analysis of variance (ANOVA) was performed. The results showed no significant differences between the groups both pretest (p = 0.158) and posttest (p = 0.158). Thus, the unequal number of trials did not affect our findings. For brevity of reporting, only the results from the key Cz electrode, and those in its immediate surroundings (i.e., C3 and C4) are presented. We selected these electrodes because they roughly overlie the frontal lobe, which consists of primary motor cortex, the premotor cortex, and the supplementary motor areas that are related to movement programming processes, all of which have been implicated in previous EEG-based golf-putting research (Babiloni et al., 2008; Cooke et al., 2014, 2015; Wang et al., 2019, 2020).

Statistical analysis

The behavior data and EEG data was exported from the motion capture system (Vicon Motion Systems), the eego system (ANT Neuro), and the NeXus-10 system (MindMedia). We further used SPSS 26 software for statistical analysis. Separated Mixed-design ANOVA and MANOVA were performed on our measures (more details in Results section). The alpha level was set at 0.05.

Results

Age

A one-way ANOVA was used for the age distributions of the three groups (FSI, TI, and S). Our data demonstrated that there was no significant effect of age, $F_{(2,27)} = 0.068$, $p = 0.935$.

Putting performance (mean radial error)

To determine the effect of EEG-NFT on golf putting performance, we ran a 3 (groups: FSI, TI, SC) × 2 (time: pretest, posttest) repeated measures ANOVA of the MRE. A repeated measures ANOVA revealed a significant interaction effect between time and group, $F_{(2,27)} = 8.220$, $p = 0.002$, and $\eta_p^2 = 0.378$. However, no significant group effect was observed in pretest ($p = 0.01$) and posttest ($p = 0.25$, Figure 3A). Follow-up *post hoc* analysis was conducted using paired t-tests to indicate that that only the FSI group exhibited performance detriment after EEG-NFT ($p = 0.013$, Figure 3B).

Subjective psychological state (attentional control level)

To examine the causal relationship between brain activity and psychological state, we ran a 3 (groups) × 2 (time) repeated measures ANOVA of the self-evaluation data (e.g., the level of attentional control). A repeated measures ANOVA revealed no significant interaction effect between time and group, $F_{(2,27)} = 2.313$, $p = 0.118$, and $\eta_p^2 = 0.146$. Despite the non-significant result, the effect size indicates a large effect, prompting further investigation through follow-up analyses. We observed that FSI group exhibited a slight decrease in the level of action control after EEG-NFT (Pretest = 4.1 ± 1.79; Posttest = 2.9 ± 0.87) although no significant difference between pretest and posttest was observed ($p = 0.119$). Similarly, there was no significant difference between pretest and posttest in TI group (Pretest = 4.35 ± 2.21; Posttest = 3.75 ± 1.84; $p = 0.297$) and SC group (5.1 ± 2.07; Posttest = 5.8 ± 2.65; $p = 0.332$).

Putting-State EEG

Brain regions

To examine the topographical specificity of 8–13 Hz at the Cz, a 3 (groups) × 2 (time) repeated measures MANOVA was carried out for the 8–13 Hz power at Fz, Cz, Pz, and Oz sites. No significant interaction was seen between group and time, $F_{(8,48)} = 0.570$, $p = 0.570$, Wilks' lambda = 0.769, $\eta_p^2 = 0.123$, and power = 0.344.

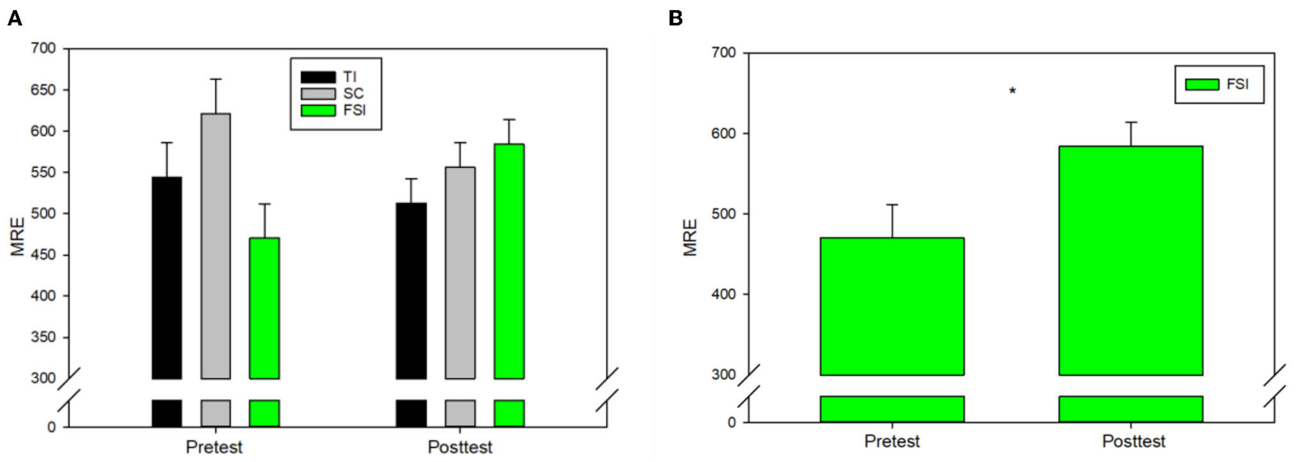

FIGURE 3
(A) Mean relative errors (MREs) for three groups. **(B)** FSI exhibited performance detriment after EEG-NFT. $^{*}p < 0.05$.

Frequency bands

To examine frequency specificity, we ran a 3 (groups) × 2 (time) repeated measures MANOVA of 4–7 Hz, 8–13 Hz, and 14–20 Hz power at Cz. We confirmed that there was no significant group and time interaction, $F_{(6,50)} = 1.359$, $p = 0.249$, Wilks' lambda = 0.739, $\eta_p^2 = 0.140$, and power = 0.482.

Variation in Mu activity

To examine the variation in Mu activity, we conducted a comparison by subtracting Mu power recorded in the posttest from Mu power recorded in the pretest. This analysis allowed us to assess the tendency of Mu power alterations after EEG-NFT. We conducted a one-way ANOVA and found no significant difference in Mu activity among the groups, $F_{(2,27)} = 1.713$, $p = 0.199$, $\eta_p^2 = 0.113$. Interestingly, we observed that only the FSI group showed a positive value (M = 0.47 ± 1.19 power), indicating an increase in Mu activity from the pretest to the posttest. In contrast, the TI group exhibited a negative value slightly (M = −0.08 ± 1.33 power), and the SC group (M = −0.53 ± 1.19 power) exhibited a negative value, suggesting a decrease in Mu activity from the pretest to the posttest (Figure 4).

Neurofeedback training

To determine the learning effect of EEG-NFT in the FSI and TI groups, we compared 8–13 Hz power at Cz during the first and last block during the training period. A 2 (groups) × 2 (block: first and last block) repeated measures ANOVA was performed. Analyses revealed no significant interaction effect between time and group, $F_{(1,18)} = 0.393$, $p = 0.539$, and $\eta_p^2 = 0.021$. However, analyses revealed a significant time main effect, $F_{(1,18)} = 14.918$, $p = 0.001$, and $\eta_p^2 = 0.453$. Follow-up analyses indicated that there had significantly increased Mu power between FSI group ($p = 0.019$) and TI group ($p = 0.029$). Thus, EEG-NFT was effective in changing the targeted brain activity in novice golfers during EEG-NFT training.

Neurofeedback training trials

To determine the effectiveness of instruction in EEG-NFT, we compared training trials in both groups. A one-way ANOVA was performed. Analyses revealed significant effect, $F_{(1,18)} = 5.832$, $p = 0.027$, and $\eta_p^2 = 0.245$ in FSI group (Mean = 12.20 ± 0.42) and TI group (Mean = 13.1 ± 1.10). The main results indicated that the FSI approach was more effective to modulate Mu power during EEG-NFT than a TI approach.

Correlation between changes in Mu rhythm and performance

Given that we observed the trend in the higher MRE as less accuracy and increased Mu rhythm in FSI group during golf putting, we further tested the correlation between Mu rhythm and MRE. To do so, we performed a correlational analysis between the percentage change in Mu activity and the percentage change in MRE from pretest to posttest in three groups. A Pearson's correlation analysis with a one-tailed test revealed that the percentage change in Mu activity was significantly positively correlated with the MRE ($r = 0.319$, $p = 0.043$, $N = 30$). It means that higher Mu power is correlated with higher MRE, suggesting lower putting accuracy in golf putting.

Control analysis

To counter the confounding effects of stress, we ran a 3 (groups) × 2 (time) repeated measures ANOVA of the subjective self-reported stress levels. Self-reported subjective stress levels in pretest and posttest were compared both between and within subjects.

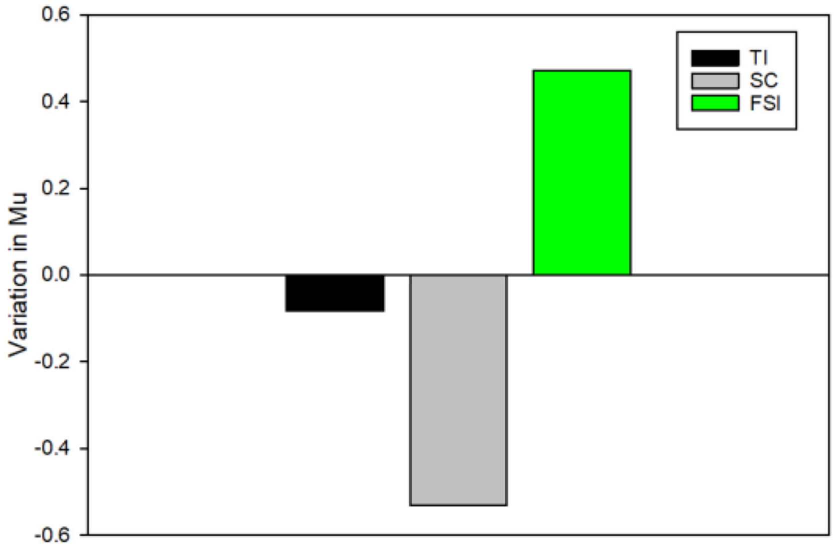

FIGURE 4
The variation in Mu activity was conducted by subtracting Mu power recorded in the posttest from Mu power recorded in the pretest. Positive value, an increase in Mu activity from the pretest to the posttest; negative value, a decrease in Mu activity from the pretest to the posttest.

A repeated measures ANOVA revealed no significant interaction effect between time and group ($p = 0.212$), nor any effect of time ($p = 1.000$). specifically, suggesting that stress levels did not significantly change during the course of the experiment and likely did not affect the results.

Discussion

The objective of this study was to investigate the impact of the FSI (function-specific instruction) approach in EEG-NFT (Neurofeedback Training) and its effects on visuomotor performance (i.e., golf). The study involved manipulating Mu power (8–13 Hz at Cz) using EEG-NFT in novice golfers. Our main finding revealed that the FSI group required fewer EEG-NFT training trials compared to the TI (Traditional Intervention) group. Following EEG-NFT, we observed the FSI group demonstrated a significant decrease in performance. However, a slight increase in Mu power and a decrease in the level of the subjective sensation of action control after EEG-NFT were observed, although these changes did not reach statistical significance ($p > 0.05$) between the pretest and posttest. However, it is worth noting that these effects exhibited a large effect size ($\eta_P^2 = 0.123$–0.140), and we observed a positive correlation between Mu power and MRE, suggesting higher mu power is correlated with lower accuracy in golf putting. These results partly complement the findings of Wang et al. (2023) and highlight the potential of the FSI approach in modulating Mu activity and its implications for visuomotor performance in the context of neurofeedback training.

Regarding the effect of Mu rhythm in EEG-NFT with the FSI approach, we observed that the FSI group showed a slight increase in Mu power after a single session of EEG-NFT. Our results demonstrated a medium-large effect size ($\eta_P^2 = 0.113$) when comparing Mu activity among the three groups. However, the group effect did not reach statistical significance. The rationale of the FSI approach in EEG-NFT is that the verbal instruction should be directly related to the specific features of brain function in order to facilitate the attainment of a desired mental state within the sports context (Chen et al., 2022b). This approach aims to minimize target-irrelevant brain activity or slower timescales during the initial learning phases by explicitly guiding individuals to enter a specific mental state. This targeted instruction helps focus on and optimize the training process, enhancing the effectiveness of EEG-NFT in sports performance (Muñoz-Moldes and Cleeremans, 2020). However, our finding is inconsistent with Chen et al. (2022b) and Wu et al. (2023) who observed that skilled golfers were able to modulate their EEG activity using the FSI approach in a single training session. The possible explanation is that skill levels may be a moderator in the effectiveness of the FSI approach in EEG-NFT. For example, Chen et al. (2022b) conducted a study on EEG-NFT with skilled golfers to investigate the effects of FSI approach and TI approach. Their research revealed that a single session of EEG-NFT using frontal midline theta (4–7 Hz) training was effective in improving performance, but this effect was observed only in the FSI group, accompanied by a decrease in frontal midline theta power after training. On the other hand, the TI group did not demonstrate performance improvement and showed no significant increase in frontal midline theta power. These findings demonstrate that skilled golfers in the FSI group were able to effectively modify their neurocognitive processing and successfully translate it into improved behavioral performance after just a single session of EEG-NFT. However, the efficacy of FSI approach may not be sufficient for participants at a novice level in our current study because novices in the early stages of learning process the rules of movement (Coker et al., 2006) and engage more cognitive resources during motor preparation (Chen et al., 2022b). This inference aligns with earlier research conducted by Wang et al. (2023) who discovered that novice golfers faced challenges in augmenting Mu power using the traditional EEG-NFT approach during golf task or when engaging in novel tasks. The FSI group employed a focused approach, requiring novices to concentrate on core components of their actions (e.g., the ball path, clubface, or shoulders) that are task-relative and adjust their mental state accordingly during EEG-NFT. Despite the potential complexity of this process for novices, the results revealed a remarkable finding: participants in the FSI group achieved the training target with significantly fewer training trials compared to the TI group. This noticeable efficiency demonstrated by the FSI group highlights the potential superiority of the FSI approach in EEG-NFT, emphasizing its value for enhancing visuomotor performance. Furthermore, it is important to consider whether novices would benefit from additional training sessions such as three (Arns et al., 2008), six (Afrash et al., 2023), and eight training sessions (Cheng et al., 2015a) to consolidate their progress and ensure the retention of acquired mental skills during visuomotor tasks. This consideration will provide a more comprehensive understanding of the implications and potential optimizations for the effectiveness of the learning process in NFT training protocols (Mirifar et al., 2017; Hung and Cheng, 2018; Cheng and Hung, 2020b). Collectively, these findings provide a new perspective that the utilization of FSI approach may need to align with a certain skill level in order to exemplify its training efficacy (Wang et al., 2020; Gong et al., 2021).

Regarding the effect of performance in EEG-NFT with the FSI approach, we observed the FSI group demonstrated a significant decrease in performance. Notably, this finding aligns with previous EEG-NFT studies, showcasing the consistency of the FSI approach in modulating performance outcomes (Kao et al., 2014; Chen et al., 2022b; Wang et al., 2023). Previous NFT studies have shown that a single session EEG-NFT can alter the performance of skilled golfers (Kao et al., 2014; Chen et al., 2022b) as well as novice golfers (Wang et al., 2023). Our study extended the findings of a previous study in skilled golfers (Chen et al., 2022b) by demonstrating that EEG-NFT with the FSI approach could also have an impact on the performance of novice golfers, although we did not observe a significant group effect in Mu activity. Interestingly, we observed a correlation between higher Mu power and decrement in putting performance (higher MRE). This finding could be explained by neurophysiological evidence suggesting that Mu rhythm reflects the allocation of cognitive resources to motor programming during the execution of goal-directed actions (Pineda, 2005; Cannon et al., 2014). Specifically, higher Mu power may indicate inhibitory motor programming, reflecting a transition from conscious control to a less conscious control process as reduced sensation of attentional control on the movement before action (Pfurtscheller, 2003; Klimesch et al., 2007).

On the other hand, lower Mu power may indicate the facilitation of task-relevant motor programming as increased attentional control on the movement during motor preparation (Cooke et al., 2015). Given that golf putting is a complex visuomotor task, reduced attentional control may not be beneficial for superior performance output (Babiloni et al., 2008; Cooke et al., 2014, 2015; Wang et al., 2023). Conversely, simple visuomotor tasks like shooting may benefit from lower levels of attentional control (Haufler et al., 2000; Del Percio et al., 2009; Bertollo et al., 2016; Cheng et al., 2017). That is, performance in the complex visuomotor task may be modulated by the subjective sensation of action control. Our study found a slight decrease in the subjective sensation of action control and an increase in Mu power among FSI group participants after EEG-NFT. Although not statistically significant, the effect size was substantial ($\eta^{P2} = 0.146$). This suggests that novice golfers may face challenges in generating precise motor output during a complex task like golf putting due to reduced attentional control. According to the stages of learning theory, conscious control of movement is crucial during the cognitive stage, particularly for novice individuals (Schmidt et al., 2018). This aligns with previous research indicating that novices allocated more attentional resources to motor control in order to improve performance in golf (Perkins-Ceccato et al., 2003). However, an interesting question is whether there is a minimum value of the subjective sensation of action control required for superior performance during a golf putting task. To answer this question, we encourage future research to investigate the correlation between different levels of the subjective sensation of action control and performance outcomes in the context of a golf putting task. Overall, our findings suggest that manipulating Mu rhythm through EEG-NFT with FSI approach can lead to performance alternation in complex visuomotor tasks, such as golf putting, although no significant group effect in Mu activity was observed. This finding may support the notion that a small change in cortical activity can translate into an alteration in performance (Vernon, 2005; Cheng et al., 2015a; Aloufi et al., 2021). However, higher Mu power in the brain may impede the execution of complex visuomotor task, while it may be benefiting the execution of simple visuomotor task, such as shooting. Further research is needed to confirm how different motor representations (simple vs. complex visuomotor skills) can modulate Mu activity during motor preparatory processes (Berka et al., 2010) and whether increased Mu activity may benefit the execution of simple visuomotor tasks.

The potential impact of stress (a confounding factor) on putting performance and Mu rhythm was investigated in our study, and it was found that stress levels did not have a significant effect on participants. Control analysis revealed no significant changes in stress levels among the three groups or between the pretest and posttest, indicating that stress remained stable throughout the experiment and likely did not influence the outcomes. Previous studies have highlighted the importance of studying the relationship between mental stress, brain dynamics, and motor performance under challenging stressors to assess the potential induction of increased connectivity (Lo et al., 2019). Hatfield et al. (2013) observed desynchrony of high-alpha power (10–12 Hz) during a competitive pistol shooting match, suggesting heightened attentional processing and reduced neural efficiency under stress conditions. The observed implication is that mental stress has the potential to negatively affect cognitive-motor performance by interfering with the coordination of sensorimotor processes and increasing the effort required for task execution (Lo et al., 2019). This finding aligns with the psychomotor efficiency hypothesis proposed by Hatfield (2018) and is further supported by studies utilizing the multi-action plan (MAP) model (Bertollo et al., 2016). Extensive research has highlighted the negative impact of excessive cognitive processing on skilled performance, leading to issues like degraded motor performance, altered motor unit activity, and reduced accuracy (Lo et al., 2019; Cheng et al., 2022). To address potential confounding factors, our study diligently controlled stress levels within and between the three groups during pretest and posttest assessments. Consequently, the observed disparities in putting performance and Mu rhythm activity between the FSI and TI groups were less susceptible to stress-related influences and more plausibly attributed to the distinct effects of the FSI approach on visuomotor performance.

Several limitations and recommendations can be discussed based on the findings of our current study. Firstly, we acknowledge the lack of statistical significance in our Mu activity during the golf putting task and subjective psychological state findings, despite observing trends and large effect sizes. This highlights the need for larger sample sizes or modifications to the experimental design to strengthen the statistical power of future studies. To address this limitation and improve the generalizability of our results, it is recommended that future studies include larger sample sizes, considering individual differences and potential subgroups within the participant pool. Secondly, our findings suggest that the effectiveness of the FSI approach in EEG-NFT may be influenced by the skill level of participants. Novice golfers in our study may not have fully benefited from the FSI approach due to their early stage of learning and limited ability to modify their neurocognitive processing. Therefore, future research should explore the interaction between skill level and the efficacy of the FSI approach. This investigation will provide a deeper understanding of how skill level moderates the effectiveness of FSI approach in EEG-NFT. Lastly, the generalizability of our findings is limited as our study specifically focused on the impact of FSI approach in EEG-NFT on visuomotor performance in novice golfers. To further neurofeedback research in sports, future studies must rigorously investigate the most effective EEG markers, especially in the context of golf putting. Recent investigations, such as those conducted by Afrash et al. (2023) and Pourbehbahani et al. (2023), have underscored the benefits of enhanced sensorimotor rhythm (SMR) and suppressed alpha neurofeedback in facilitating long-term motor learning among novice golfers. Cheng et al. (2015a) extended this research by correlating higher sensorimotor power at the Cz point with enhanced performance in skilled golfers. This body of work underlines the need for comprehensive research to pinpoint and validate the most efficacious EEG markers. Focused research is imperative for devising accurate and impactful neurofeedback training methods in sports, particularly to improve complex visuomotor skills, such as golf. Additionally, understanding how the FSI approach can be adapted and refined for various sports, ranging from simple visuomotor tasks like shooting to complex ones like golf putting, archery, and penalty kick (Chang and Hung, 2020), and for different skill levels from novices to experts, is crucial. Furthermore, adopting long-term training protocols is crucial to explore the lasting effects of FSI approach in EEG-NFT and assess the retention of acquired mental skills. Future studies could incorporate extended training interventions, such as 8-session training programs (Cheng et al., 2015a; Christie et al., 2020), to evaluate the durability and transferability of these skills. This will provide valuable insights into the long-term benefits of FSI approach in EEG-NFT. Collectively, addressing the limitations of our study and pursuing these recommendations will contribute to a more comprehensive understanding of the impact of the FSI approach in EEG-NFT, its efficacy across different skill levels, and its potential applications in enhancing visuomotor performance.

The results of our study offer meaningful implications for real-life application in sports coaching and practice. Coaches and practitioners can utilize these findings to design more effective and targeted training programs. Our study suggests that the effectiveness of the FSI approach in EEG-NFT may vary depending on the skill level of participants. Novice golfers in our study did not fully change their EEG activity and mental state during visuomotor task from the FSI approach, possibly due to their early stage of learning and limited ability to modify their neurocognitive processing. Coaches and practitioners should take into account the skill level of athletes when implementing the FSI approach in EEG-NFT, as it may be more effective for skilled individuals who can effectively modify their neurocognitive processing and translate it into improved performance. Secondly, our study highlighted the different effects of attentional control on performance in complex visuomotor tasks like golf putting compared to simple visuomotor tasks like shooting. Reduced attentional control may be detrimental to performance in complex tasks but beneficial in simple tasks. Coaches and practitioners should be aware of the subjective sensation of action control required for different tasks and tailor training approaches accordingly. This understanding will assist in optimizing performance outcomes and facilitating skill development. Lastly, for long-term training protocols, our findings indicated that participants in the FSI group required fewer training trials to reach the training target compared to the traditional intervention (TI) group. To enhance the effectiveness and retention of acquired mental skills during visuomotor tasks, coaches and practitioners may consider implementing extended training protocols, such as 8-session interventions (Cheng et al., 2015a; Hung and Cheng, 2018; Cheng and Hung, 2020a). This will allow novice athletes to consolidate their progress and ensure the long-term benefits of FSI in EEG-NFT (Mirifar et al., 2017; Xiang et al., 2018; Onagawa et al., 2023). In summary, our study emphasizes the importance of considering skill level, understanding the complexity of visuomotor tasks and implementing long-term training protocols when utilizing the FSI approach in EEG-NFT. These insights can guide coaches and practitioners in designing scientific training programs that effectively enhance visuomotor performance.

This study aimed to investigate the impact of implementing the function-specific instruction (FSI) approach in EEG neurofeedback training (NFT) on visuomotor performance, specifically in the context of golf. The study highlights the potential of the FSI approach in EEG-NFT for influencing brain activity and visuomotor performance. However, the effectiveness of the FSI approach in EEG-NFT may vary depending on participants' skill level. Novices may need additional training sessions in EEG-NFT with FSI approach to consolidate progress and retain acquired mental skills. In complex visuomotor tasks, attentional control may play a crucial role, as higher Mu power correlates with lower performance. To conclude, these findings provide valuable insights for optimizing EEG-NFT protocols and enhancing visuomotor performance. Recommendations for future studies include exploring skill-level specificity, implementing long-term training interventions, and studying diverse populations and motor tasks.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Ethics Committee of Bielefeld University. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

K-PW: Conceptualization, Funding acquisition, Investigation, Methodology, Software, Supervision, Writing – original draft, Writing – review & editing. M-YC: Conceptualization, Methodology, Validation, Writing – original draft, Writing – review & editing. HE: Data curation, Investigation, Methodology, Validation, Writing – review & editing. TS: Resources, Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Interpersonal behaviors in sports context: Spanish adaptation and measurement invariance

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Introduction: The interpersonal behavior questionnaire (IBQ) is an instrument that measures support and thwarting interpersonal behaviors based on the self-determination theory (SDT). The aim of this work was to adapt the IBQ to the Spanish spoken in Mexico and to examine its psychometric properties (structural validity, discriminant validity, composite reliability, factorial invariance, and nomological validity) in a sample of athletes.

Methods: For this purpose, 472 athletes (average age 17.15 years; SD = 1.47) completed a question booklet.

Results and discussion: Confirmatory factor analysis supported the structure of six related factors, three factors of behaviors that support autonomy, competence, and relatedness, and three factors of behaviors that thwarting them. The internal consistency of each factor was also supported, as well as the average variance extracted. However, the discriminant validity between the factors of competence and relatedness in their dimensions of support, on the one hand, and thwarting, on the other, is questioned. Factorial invariance was confirmed across gender (men and women) and sport type (individual and team). Nomological validity is in accordance with theory and empirical literature. More studies of the IBQ in sport are necessary to see if these results are a fortuitous product or if they manifest themselves consistently.

KEYWORDS

multi-group analysis, interpersonal behavior, psychological needs, sport, validating a measure

Introduction

A factor that could explain how and why the people we interact with have an impact on the quality of our psychosocial experiences, is the way they influence our psychological needs (Sheldon, 2011). In sports, the coach could be considered the main person for athletes, thus playing an important role in the satisfaction of psychological needs (Ryan and Deci, 2007) or in the frustration of them, since the coach is the one who sets goals, supervises training, models attitudes, creates strategies, handles competition situations, and many other activities where the athletes' pressure to demonstrate a certain level of performance can sometimes make the coach treat his/her athletes inadequately (Mageau and Vallerand, 2003).

Self-determination theory (SDT; Ryan and Deci, 2000) proffers that people have three basic psychological needs (BPN), autonomy (i.e., acting in line with their own interests and values), competence (i.e., experiencing a sense of effectiveness), and relatedness (i.e., experiencing a sense of connectedness with other people). These are innate, are present in all stages of development, and are universal throughout all cultures (Deci and Ryan, 2002). The satisfaction of these BPN by the social context provides people the psychological nutrients necessary for a person's optimal functioning, which further impacts the quality of motivation, promoting positive or negative consequences on wellbeing, because based on this theory, the conduct's internalization process requires the support and satisfaction of the three BPN (Deci and Ryan, 2002).

The social context includes both the sport's structure (i.e., competitive environment), as well as the people within the sport (i.e., coach). The people of the social context can support or thwart the individual perception of the BPN depending on their interpersonal styles, a construct employed to characterize the way people interact among themselves during social exchanges (Deci and Ryan, 2002). SDT proffers that interpersonal conducts of coaches play an important role in the experiences of athletes based on the degree in which these conducts support or thwart the BPN (Deci and Ryan, 1985); for example, when the people of the sport context exhibit interpersonal conducts that support autonomy, then they will promote BPN satisfaction in the athlete (Deci and Ryan, 1985).

Additional to supporting the autonomy, SDT proposes the existence of three interpersonal styles that support BPN, and three interpersonal styles that thwart BPN. The conducts that support autonomy (AS) are described as those that provide explanation for the tasks, recognize the perspectives and viewpoints of others, and bring opportunities for initiative in tasks (Mageau and Vallerand, 2003; Mageau et al., 2015). The conducts that thwart autonomy (AT), or controlling conducts, include using conditional rewards, using intimidating or coercive language, asking for tasks without a justification, and making use of an excessive personal control (Bartholomew et al., 2009). The conducts that support competence (CS) include the use of realistic expectations, the importance of learning, providing positive feedback, recognizing improvement, believing in people's ability to reach goals, and encouraging them to improve their skills (Sheldon and Filak, 2008). The conducts that thwart competence (CT) consist in emphasizing on other's mistakes, discouraging people from trying to carry out difficult tasks, sending the message that somebody is incompetent, and doubting others' ability to improve (Sheldon and Filak, 2008; Reeve, 2015). The conducts that support relatedness (RS) include showing that you understand, support and care for others, displaying warmth (Jones et al., 2004), and showing an interest in the activities of others. Lastly, the conducts that thwart relatedness (RT) include being distant from others, excluding persons from the group or activities, not listening, and not being available when necessary (Sheldon and Filak, 2008; Rocchi et al., 2017).

These constructs are not opposites, and people can engage in both interpersonal conducts of supporting and thwarting (Vansteenkiste and Ryan, 2013), in other words, they can coexist simultaneously within one context (Vansteenkiste et al., 2020).

Of these six interpersonal theorized styles, AS is the one that has received the most attention, partly because the need for autonomy is at both the most exclusive of the SDT and the most controversial. Thus, to this day, research has focused mainly on AS, supporting that the latter predicts the satisfaction of the BPN in sports (Adie et al., 2008; Balaguer et al., 2008; Álvarez et al., 2013; Morillo et al., 2018; Heredia-León et al., 2023). The controlling style (AT) has been studied to a lesser degree, even though it is necessary to measure supporting as well as thwarting conducts, since the absence of support does not imply the presence of thwarting conducts (Sheldon, 2011; Vansteenkiste et al., 2020). For this reason, some studies have simultaneously analyzed AS and AT, where AS leads to greater autonomous motivation, positive affects, and self-confidence; while AT leads to more controlled motivation, amotivation and negative affects (Isoard-Gautheur et al., 2012; Haerens et al., 2015; Behzadnia et al., 2018; Pineda-Espejel et al., 2020).

The aforementioned empirical evidence suggests that the socializing agents that support autonomy also tend to support the competence and relatedness needs. Thus, when coaches support autonomy, they often also support other needs of their athletes (i.e., competence and relatedness). In general, AS has been seen as the promoter of satisfaction of autonomy and relatedness, nevertheless, the question emerges regarding to what happens to the other interpersonal conducts proposed by SDT (i.e., CS, RS, CT, RT), or if supporting autonomy is enough to favor the motivational processes.

In the sports context, little is known about the other four interpersonal styles proposed by SDT, and their influence in the satisfaction and frustration of the BPN of athletes (Rocchi et al., 2017). Maybe it's due to the lack of valid instruments to measure the six interpersonal styles in the aforementioned context.

It's important to measure the perception of the three types of interpersonal conducts that support the needs, and the three types of interpersonal conducts that thwart the same, to be able to know how coaches can nurture the psychological needs of their athletes. That is why progress has been made in the efforts to measure each one of the six interpersonal styles that support/thwart the BPN, for example, the observational guide of Haerens et al. (2013) within the context of physical education. One weakness is that the observation analyzes the frequency of conducts but not whether those conducts are perceived as being supporting or thwarting. On the other hand, some instruments only measure autonomy support, ignoring the role of competence and relatedness support, while others measure the support of the three BPN, and others measure the thwarting of BPN, instead of measuring them together as a whole. For this reason, in some cases various instruments are used to measure on one hand the support of BPN, and on the other the thwarting of the same, which may lead to conceptual differences among the different tools, as well as inconsistencies in measurements (Rodrigues et al., 2019).

In light of the need to measure the degree in which interpersonal conducts are either supporting or thwarting, focusing on conducts and not feelings, in other words, the current perceptions of the conducts, the Interpersonal Behaviors Questionnaire applied to the context of sports (IBQ in sport; Rocchi et al., 2016). It consists of a self-report that assesses the athlete's perception of the coach's interpersonal behaviors that support or thwart the athlete's basic psychological needs. Furthermore, the IBQ has been applied to the context of physical exercise with users of gymnasiums in the Portuguese language (Rodrigues et al., 2019), it has been translated to Spanish and applied to the context of physical education by Burgueño and Medina-Casaubón (2021), and translated into Romanian applying it to the sports context (Alexe et al., 2023). These three versions have demonstrated adequate structural validity, adequate reliability, invariance across sex, as well as nomological validity.

Rocchi et al. (2017) mentioned that in order to confirm IBQ's universality and applicability in different cultures, it is necessary to analyze the instrument in different contexts and populations, as well as replicating the invariance in other groups with different characteristics. Therefore, validation in a sample of Mexican athletes, as well as evidence of invariance increases the scientific evidence contributing to development of knowledge about the universality of the interpersonal behaviors. Additionally, SDT proffers that the three types of interpersonal conducts are essential, which is why it is important to connect them with the three types of BPN to determine how each dimension of the interpersonal conducts are conceptually different from each other.

Since few Spanish-language instruments simultaneously examine the six dimensions of interpersonal behaviors in the sport context, not much is known about the role of the magnitude of behaviors that support/thwart competition and relatedness, and their effects they may have on motivational experiences in sport. Therefore, this study aims to adapt the IBQ to the Spanish spoken in Mexico and to examine its psychometric properties (factor structure, reliability, factor invariance-men vs. women, team vs. individual sport, adolescents vs. young adults-) in a sample of athletes, and then to examine its nomological or criterion validity by relating the subscales to BPN satisfaction and frustration.

Methods

Participants

The information was gathered during the first 2 weeks of the 2022 CONADE's National Games, National stage, based in Mexicali, México. The selection of the sample was non-probabilistic by convenience, depending on the sports competition and the athletes that could be reached. The sample size was obtained with the ratio of estimated parameters between 10:1 (Tabachnick and Fidell, 2012). A total of 472 federated athletes and national competition level (250 men, 218 women, the rest of the participants preferred not to reveal their gender) between the chronological ages of 13 and 22 years old (M = 17.15; SD = 2.81) participated. Information reported an average frequency of training of 4.68 days a week (SD = 1.42), for 3.32 h per day on average (SD = 1.41). They had an average training experience in their sport of 5.74 years (SD = 3.00). The sports accessed for data collection were field hockey (n = 192), fencing (n = 148), modern pentathlon (n = 50), bowling (n = 34), soccer (n = 24) and wrestling (n = 24).

Instruments

The Interpersonal Behaviors Questionnaire Spanish versión (Burgueño and Medina-Casaubón, 2021) was used. This instrument measures the athletes' perception about the interpersonal behaviors of their coaches. It consists of 24 items which measure six BPN interpersonal supporting and thuwarting behaviors proposed by the SDT, which make up the six subscales of the instrument (AS, AT, CS, CT, RS, RT). It is answered with a seven-point Likert scale ranging from 1 (*completely disagree*) to 7 (*completely agree*).

To measure the athletes' BPN, both in its satisfaction and its frustration, the Spanish version of the Basic Psychological Need Satisfaction and Frustration Scale was used (BPNSFS; Pineda-Espejel et al., 2023). It consists of 24 items clustered in six factors according to the satisfaction and the frustration of the competence needs (e.g., "I feel capable about what I do"/"I feel insecure about my skills"), autonomy needs (e.g., "I feel like I do what I really want"/"I feel under pressure to do a lot of things"), and relatedness needs (e.g., "I feel affection for the people I spend time with"/"I feel excluded from the group I want to belong to"). Each factor is made up of four items, which are answered with a five-point Likert scale ranging from 1 (*completely false*) to 5 (*completely true*).

Procediment

The study received the ethical approval of the university of the first author (UABC-1152). The Spanish version of the IBQ had a contextual linguistic adaptation to the Spanish spoken in Mexico, so grammatical adjustments were made to make it more appropriate to the context. After having the final of the instrument, the first contact was with the organizing institution of the event (Institute of Sport and Physical Culture of Baja California) to obtain its authorization for its application during the event. Subsequently, sports delegates and coaches were informed about this study during the technical board of each sport. We went to the competition sports facilities to request the support of the coaches so that their athletes could answer the questionnaires. Data collection was carried out in the training session prior to the competition. Athletes of legal age were informed in writing and gave their consent to participate; in the case of minors, consent was provided by the coach, since most dads or moms were not present at that time. All participants were treated in accordance with the ethical guidelines of the American Psychological Association, so that the confidentiality and anonymity of the responses are guaranteed.

Data analysis

First, it was found that the database did not have atypical responses or lost values. Descriptive and univariate normality statistics of the items were analyzed with the SPSS 23 program. Then, to examine the factor structure, confirmatory factor analysis (CFA) was carried out with the Mplus program, and the maximum plausibility estimation method (ML), where age was not included as a covariate. The model evaluation was carried out using absolute and incremental adjustment indices. These included the RMSEA and its 90% confidence interval (90 CI), RSMR, TLI, and CFI. Values equal to or less than 0.08 for RMSEA indicate good fit (Hair et al., 2019), with values equal to or less than 0.10 for the upper limit of 90 IQ (Byrne, 2016). For the RMSR, values equal to or less than 0.08 reflect an optimal setting when used in combination with other indices (i.e., RMSEA) more than when used in isolation (Hu and Bentler, 1999); and for CFI and TLI values ≥0.90 indicate acceptable adjustment (Hu and Bentler, 1999).

The equivalence of the instrument with a multigroup CFA was also examined to test factorial invariance through gender, age group (teenagers or young adults) and type of sport (team or individual). Differences no >0.01 for CFI indicate irrelevant practical differences (Cheung and Rensvold, 2002); the same for RMSEA when the increases are <0.015.

Additionally, a reliability analysis was carried out with McDonald's omega coefficient, where values >0.70 show good reliability (Hair et al., 2019), and the average extracted variance (AVE) was tested, where values >0.50 indicate good fit (Hair et al., 2019). Finally, the validity of the criterion was analyzed through the relationship with the satisfaction and frustration of each of the BPNs.

Results

Factorial analysis confirmatory

CFA confirmed the measurement model formed by a structure of six related factors, since data offers a good representation of reality: χ^2 (237) = 578.85, $p < 0.001$; RMSEA = 0.06 (90% CI = 0.05–0.07); CFI = 0.92; TLI = 0.91; SRMR = 0.07. All items saturated over 0.40, with a significance of $p < 0.01$ (Table 1). However, the phi correlation matrix (Table 2) showed high correlations between the latent factors of CS and RS (phi = 0.94) on the one hand, and between CT and RT (phi = 0.95) on the other, suggesting a lack of discrimination between these factors.

Additionally, the correlation matrix (Table 2) confirmed positive associations between each of the three factors measuring the perception of BPN-supportive interpersonal behaviors, on the one hand, and between each of the three factors measuring the perception of BPN-frustrating interpersonal behaviors, on the other hand.

Table 2 shows that, in terms of reliability, the omegas coefficients were satisfactory, exceeding the criterion of 0.70 (McDonald omega range of 0.97–0.99). While the AVE indicated that the constructs explain more than half of the variance of all the indicators that compose them, except for the AT factor.

Factorial invariance

To analyze factorial invariance across gender, age group (adolescents vs. young adults), an sport type (individual vs. team) a series of multisample confirmatory factor analyses were performed (Table 3). In the gender case, these indicated that, based on the differences in RMSEA the six related factor structure of the instrument is invariant between males and females athletes, since comparisons of this index between the nested models with restrictions confirmed equivalences in all four models. That is, first the levels of configural invariance (M1) were confirmed. Then, by comparing M2 with the previous model, the measurement invariance could be confirmed. When comparing M3 with M1, scalar equivalence (strong invariance) was confirmed. Finally, the comparison of M4 with M1 could confirm the residual equivalence (strict invariance) (Byrne, 2016). In the age groups, the results rejected the ivariance hypothesis at all levels between adolescents and youg adults. Finally, the results supported the strict invariance across the sport type, guiven that factorial, covariance and error measurement model equivalence was confirmed.

Nomological validity

Regarding the association of the six factors that make up the IBQ in sport with theoretically related constructs, Table 4 shows that each BPN's supportive interpersonal behavior was positively associated with BPN satisfaction levels and negatively associated with each BPN's frustration levels. The opposite was true for BPNs' interpersonal behaviors of frustration.

Discussion

This present study was conducted with the aim of adapting the IBQ to Spanish spoken in Mexico, to examine its psychometric properties in a sample of athletes, and then to examine the nomological or criterion validity by relating the subscales to BPN satisfaction and frustration.

The results support the construct validity of the instrument, since the six latent factor structure is confirmed, in addition, it shows adequate reliability, and it can be said that each construct explains more than half of the variance of the items that compose it, with the exception of the AT factor, however, AVE values slightly below 0.50 can also be considered acceptable (Hair et al., 2019). However, the discriminant validity between latent factors is not satisfactory, since some factors correlate above 0.85 (i.e., CS with RS, y CT with RT), which has happened in other studies of linguistic adaptation and validation in the sports context (Alexe et al., 2023), and of validation to physical education (Burgueño and Medina-Casaubón, 2021) where AS with CS, AS with RS, CS with RS or CT with RT correlated above 0.90; although there are other studies where discriminant validity is confirmed (Rocchi et al., 2017; Rodrigues et al., 2019). This may mean that in the sporting context a coach who performed more CR could also promote more RS. This discrepancy may be due to the fact that across cultures there may be variations in the functional significance or meaning that individuals attribute to a behavior relevant to psychological need.

Regarding nomological validity, the latent factors are associated with satisfaction/frustration for each BPN, as theorized from SDT, and coincides with the validation studies of Rocchi et al. (2017), Rodrigues et al. (2019), and Alexe et al. (2023). This helps to support that the constructs are conceptually distinct from each other. It also suggests that socializing agents capable of nurturing one need often simultaneously support other needs, even if at different intensity, as noted by some authors (Baard et al., 2004; Skinner et al., 2005; Rocchi et al., 2017). In the same way, authority figures who exhibit interpersonal thwart behaviors one need appear to thwarting the other needs to different extents. In this aspect, the latent factors of the measurement instrument represent the constructs theorized in SDT on interpersonal behaviors.

Regarding the multigroup analysis, this supports that the structure of the measurement model is equivalent in the different groups (men vs. women, team vs. individual sport) since the results of the differences in RMSEA results empirically support that the different groups of Mexican athletes interpret the meaning of support and thwart interpersonal behaviors similarly. Although the differences in CFI exceed the suggested limits across age, differences in RMSEA less than 0.015 can support invariance (Chen, 2007). However, it is suggested to take these results with caution, because RMSEA tend to over reject an invariant model when sample size is small (Chen, 2008). These results is added to the evidence of universality and generalizability of the dimensions of interpersonal behaviors related to BPN support and thwarting, what will allow analyzing possible

TABLE 1 Descriptive statistics, normality, and factorial weights of the items that make up the IBQ in sport.

Item	λ	ε	R^2	*M*	*SD*	Asymmetry	Kurtosis
Interpersonal behavior of autonomy support (AS)							
1 Gives me the freedom to make my own choices (Me da libertad de tomar mis propias decisiones)	0.68	0.19	0.47	5.64	1.56	−0.99	0.08
7 Supports my decisions (Apoya mis decisiones)	0.78	0.21	0.61	5.81	1.42	−1.27	2.45
13 Supports the choices that I make for myself (Apoya las elecciones que hago)	0.80	0.17	0.65	5.62	1.51	−1.02	0.35
19 Encourages me to make my own decisions (Me anima a tomar mis propias decisiones)	0.76	0.18	0.59	5.59	1.56	−1.10	0.63
Interpersonal behavior of competence support (CS)							
2 Encourages me to improve my skills (Me anima a mejorar mis habilidades)	0.80	0.13	0.64	6.10	1.32	−1.07	2.64
8 Provides valuable feedback (Me proporciona correcciones útiles)	0.66	0.16	0.43	6.09	1.40	−1.70	2.45
14 Acknowledges my ability to achieve my goal (Reconoce mi habilidad para lograr mis metas)	0.81	0.12	0.66	5.99	1.35	−1.33	1.18
20 Tells me that I can accomplish things (Me dice que puedo lograr las cosas)	0.83	0.10	0.70	6.05	1.44	−1.70	2.48
Interpersonal behavior of relatedness support (RS)							
3 Is interested in what I do (Se interesa por lo que hago)	0.87	0.08	0.77	5.98	1.44	−1.48	1.58
9 Takes the time to get to know me (Se toma el tiempo para saber sobre mí)	0.91	0.08	0.83	5.59	1.68	−1.15	0.48
15 Honestly enjoy spending time with me (Realmente le gusta pasar tiempo conmigo)	0.85	0.08	0.72	5.25	1.55	−0.72	−0.01
21 Relates to me (Se relaciona conmigo)	0.84	0.08	0.71	5.51	1.68	−0.94	0.02
Interpersonal behavior of autonomy thwarting (AT)							
4 Pressures me to do things their way (Me presiona para hacer las cosas a su manera)	0.46	0.05	0.22	3.48	1.94	0.28	−1.11
10 Imposes their opinions on me (Me impone sus ideas)	0.55	0.06	0.30	4.22	2.11	−0.18	−1.28
16 Pressures me to adopt certain behaviors (Me presiona para comportarme de cierta forma)	0.67	0.04	0.45	3.34	2.05	0.33	−1.19
22 Limits my choices (Limita mis decisiones)	0.69	0.03	0.48	2.77	1.99	0.82	−0.62
Interpersonal behavior of competence thwarting (CT)							
5 Points out that I will likely fail (Me dice que seguramente fallaré)	0.84	0.04	0.70	2.28	1.95	1.26	0.11
11 Sends me the message that I am incompetent (Me envía mensajes de que soy torpe)	0.90	0.04	0.82	2.24	2.00	1.33	0.21
17 Doubts my capacity to improve (Duda de mis capacidades para mejorar)	0.86	0.05	0.74	2.50	1.99	1.01	−0.37
23 Questions my ability to overcome challenges (Cuestiona mis habilidades para superar algún desafío)	0.79	0.05	0.63	2.58	1.91	0.95	−0.38
Interpersonal behavior of relatedness thwarting (RT)							
6 Does not comfort me when I am feeling low (No me consuela cuando me siento mal)	0.66	0.06	0.44	3.18	2.20	0.45	−1.31
12 Is distant when we spend time together (Es distante cuando pasamos tiempo juntos)	0.90	0.05	0.81	2.84	2.95	0.86	−0.52
18 Does not connect with me (No conecta conmigo)	0.86	0.05	0.75	2.48	1.79	0.82	−0.73
24 Does not care about me (No se preocupa por mí)	0.82	0.05	0.68	2.31	2.01	1.20	−0.01

λ, factorial weight; ε, standard error; *M*, average; *SD*, standard deviation.

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TABLE 2 Matrix of phi correlations between the latent factors of IBQ in sport, AVE, and reliability (diagonal).

Interpersonal behavior of …	AS	CS	RS	AT	CT	RT
Autonomy support (AS)	0.92					
Competence support (CS)	0.30**	0.96				
Relatedness support (RS)	0.28**	0.94**	0.97			
Autonomy thwarting (AT)	−0.49**	0.23**	0.31**	0.96		
Competence thwarting (CT)	−0.07	−0.81**	−0.72**	0.12	0.98	
Relatedness thwarting (RT)	−0.12*	−0.82**	−0.84**	0.03	0.95**	0.98
AVE	0.57	0.60	0.75	0.36	0.72	0.66

**$p < 0.01$; *$p < 0.05$.

TABLE 3 Goodness-of-fit rates for each of the models tested on the factorial invariance of the IBQ in sport between men and women.

Model	χ^2 (d.f.)	RMSEA	CFI	ΔRMSEA	ΔCFI
Across gender					
M1_ configural invariance	888.69 (474)*	0.072	0.940		
M2_ metric invariance	903.49 (492)*	0.075	0.920	0.003	0.020
M3_ intercept invariance	968.98 (516)*	0.077	0.900	0.005	0.040
M4_ invariance of intercepts and errors	983.56 (540)*	0.074	0.900	0.002	0.040
Across age					
M1_ configural invariance	945.42 (474)*	0.080	0.850		
M2_ metric invariance	987.25 (492)*	0.100	0.830	0.020	0.020
M3_ intercept invariance	1044.42 (516)*	0.100	0.820	0.030	0.030
M4_ invariance of intercepts and errors	1115.19 (540)*	0.100	0.800	0.050	0.030
Across sport type					
M1_ configural invariance	1117.73 (474)*	0.076	0.909		
M2_ metric invariance	1141.07 (492)*	0.066	0.900	0.010	0.009
M3_ intercept invariance	1198.63 (516)*	0.065	0.901	0.011	0.008
M4_ invariance of intercepts and errors	1297.05 (540)*	0.067	0.899	0.009	0.010

*$p < 0.001$; d.f., degrees of freedom.

TABLE 4 Correlation matrix with outcome variables for the IBQ in sport.

	Autonomy satisfaction	Competence satisfaction	Relatedness satisfaction	Autonomy frustration	Competence frustration	Relatedness frustration
AS	0.32**	0.23**	0.09	−0.16*	−0.15*	−0.28**
CS	0.37**	0.26**	0.16*	−0.15*	−0.21**	−0.35**
RS	0.37**	0.28**	0.19**	−0.05	−0.12	−0.31**
AT	−0.23**	−0.07	−0.10	0.35**	0.27**	0.42**
CT	−0.33**	−0.18*	−0.23**	0.25**	0.35**	0.53**
RT	−0.36**	−0.18*	−0.15*	0.30**	0.38**	0.53**
M	3.81	3.97	4.19	2.84	2.69	2.25
SD	0.77	1.16	1.43	1.02	0.97	0.98

M, average; *SD*, standard deviation; *$p < 0.05$; **$p < 0.01$.

differences in the perception of the six specific dimensions of interpersonal behaviors, as in other studies (Burgueño and Medina-Casaubón, 2021; Alexe et al., 2023). Nevertheless, in the case of age group, the differences in the adjustment indices show that adolescents and young adults interpret the meaning of the items in different ways.

With this self-report at the contextual level, athletes can inform their perceptions of their coach's interpersonal behaviors. It can be used in the sport context to more accurately measure the role of the six dimensions of supportive and thwarting interpersonal behaviors in predicting BPNs in both satisfaction and frustration, with the understanding that BPN frustration and satisfaction may have different antecedents (Bartholomew et al., 2011). Thereby extending research in sport motivation.

It may then promote future research initiatives that test the complete sequence proposed by Vallerand (1997), at the contextual level, of social factors (i.e., the role of the six types of supportive/thwarting interpersonal behaviors), psychological mediators, motivational types and consequences.

This study is important as the context of sport differs in the degree to which such BPN are generally supported or thwarted (Ryan et al., 2019), particularly coaches' behaviors may be more or less supportive or thwarting of BPN. From a theoretical perspective, it contributes to the validation and generalization of the construct of interpersonal behaviors in sport in the Mexican population. From a practical perspective, it provides an instrument adapted to the sporting and linguistic context in Mexico, which can be used with adolescent and young athletes of different modalities to reliably evaluate the six types of interpersonal behaviors proposed by the SDT.

However, this study has limitations such as characteristics of the sample, which was not representative of Mexican sport context, and included adolescent and young athletes, which could influence the results due to the comprehension of the items. Therefore, it is suggested to test with other ages, levels of competition and with different Spanish-speaking populations. Studies could also be conducted to learn how perceptions of interpersonal behaviors change over short periods of time. This is a self-report, so it could be triangulated with other more qualitative measures to confirm whether these measures correspond to actual behaviors. On the other hand, the IBQ in sport self was not included in this study, so it is also suggested to validate the instrument with a sample of coaches who report on their own perceptions of their interpersonal behaviors. In general, more studies are needed to continue to test the psychometric properties and extend the validity of the Spanish version of the instrument in the sport context to analyze the possible lack of discriminant validity between the CT-RT and CS-RS subscales, and see if these results are a fortuitous product or if they manifest themselves consistently (Bollen, 1989).

Conclusion

This study supports the applicability of the Spanish version of the IBQ in Mexican sport, since the factorial structure of the instrument is confirmed, the factors correlate with other theoretically related variables, and it shows to be reliable for measuring athletes' perceptions of the six types of interpersonal behaviors that their coaches may adopt; although the discriminant validity is questionable. Therefore, this self-report can be applied in the sport context to measure the perception of interpersonal behaviors that athletes report from their coach. This instrument joins those already existing within the literature and measurements within SDT.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Universidad Autónoma de Baja California. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

HP-E: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft. RM-S: Methodology, Writing – original draft. VM-S: Data curation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Stress and sport performance: a PNEI multidisciplinary approach

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Stress control is essential for avoiding a state of anxiety in sport competitions, as this state may have negative effects on other psychological variables of athletes, decreasing their self-confidence and harming their attentional control. In the present contribution a distress intervention model developed from a PNEI perspective will be sketched out. Our theoretical-methodological proposal consists of the definition of an integrated protocol of psycho-biological assessment and intervention on the allostatic load and on the levels of distress/eustress detectable in the sport environment, in relation to the person's health/well-being condition and the impact of this condition on the quality of sport performance.

This paradigm has the potential to explore both the psychological dimension of stress management and the psycho-educational and psycho-physical dimension, according to a truly integrated approach to the athlete's health and psychophysical well-being. Its multidisciplinary nature requires close cooperation between different professional figures, such as the mental coach, psychologist, nutritionist, osteopath, and physiotherapist, as well as biologists, physicians and kinesiologists, both in planning and in implementation and monitoring at all stages. The potential impact of the model on sport performance will be deeply discussed.

KEYWORDS

stress, sport performance, allostatic load, coping, stress management interventions

1 Introduction

1.1 Stress and performance

1.1.1 Stressors in sport

In the sports arena, athletes face numerous stressful situations, which are generated from different sources. In general, situations that are regarded as challenging, potentially threatening, or requiring a considerable waste of resources to deal with (coping strategies) are categorized as stressors. These may include environmental factors related to competitive performance, such as participation in major competitions, rivalry with an opponent, media attention, unsatisfactory refereeing, unfavorable weather conditions, or a decline in performance (Ntoumanis and Biddle, 1998). Aspects related to the sports organization of which the athlete is a part, such as economic insecurity, communication problems with the coach or teammates in team sports, training methodologies, a change of role, conflicts of values (Buceta, 1985), can also be a source of stress. Likewise, events that are part of an athlete's life, such as the death or illness of a close person, or a change of residence can affect anxiety and stress levels in an athlete (Arnold and Fletcher, 2021). In addition to external factors, numerous internal factors can be a source of stress. Even if the study of personality in sports psychology is primarily focused on investigating the associations between personality, participation, and athletic achievement (Aidman and Schofield, 2004; Allen et al., 2013; Allen and Laborde, 2014; Steca et al., 2018), such association may also influence perceived stress in athletes. A variety of motivational and dispositional variables that are correlated with sports performance and success has been investigated (e.g., Steca et al., 2008; Baretta et al., 2017).

Exposure to such stressors can negatively affect an athlete's health (Simms et al., 2020), well-being (Roberts et al., 2019) and performance (Arnold et al., 2017; Arnold and Fletcher, 2021). Conversely, some studies have shown how certain stressors, including injuries, can be associated with more positive outcomes (e.g., stress-related growth, Roy-Davis et al., 2017). The literature on this topic does not always agree in identifying stressors that negatively affect the athlete, for several reasons. The potential effects such situations may have are largely moderated by the athlete's appraisal of stressful situations. The stress response is determined by three factors (Anderson and Williams, 1988): personality characteristics (rigidity/flexibility, locus of control, trait anxiety, achievement motivation, sensation seeking); the athlete's personal history of coping with stressors, regarding both severe and minor events; coping resources and social support. Furthermore, most research has focused on the analysis of individual stressors (e.g., competition, organizational or personal factors) rather than exploring their cumulative effects on health (Fletcher et al., 2006). To assess the effects of negative events on performance, several studies recurred to self-report checklists (Moore et al., 2018), which can assess the frequency of a relatively small number of events (such as the loss of a loved one) while neglecting some key dimensions of stressors (such as magnitude and severity; Slavich, 2019).

1.1.2 Effects of stressors in sport

Many athletes struggle to implement functional strategies to cope with the causes and consequences of stressful events, with outcomes that can have a very negative impact on their performance and health. Such difficulties in managing high levels of anxiety and stress in sport can lead to a variety of outcomes, including unsatisfactory performance, negative thought patterns, negative emotions and depressive symptoms, and injuries (Buceta, 1985). In contrast, athletes who possess a broad repertoire of coping strategies govern stressful situations more effectively and achieve optimal levels of anxiety/arousal. This has a positive impact on performance.

According to the anxiety/stress spiral model (Cox, 1998) athletes with high levels of trait anxiety manifest distress-related symptoms more frequently (Man et al., 1995). Three distinct dimensions are involved in competitive anxiety experience: cognitive anxiety, somatic anxiety and self-confidence (Hardy, 1990, 1996; Martens et al., 1990; Maynard and Cotton, 1993; Hardy et al., 2004). While an adequate level of somatic anxiety can be beneficial (an inverse U-shaped correlation with performance has been observed; Burton, 1988), increased cognitive anxiety negatively correlates with performance (Cox, 1998). In other words, improving performance requires reducing cognitive anxiety and negative thoughts, and finding the optimal level of somatic anxiety. However, it appears that the construct of sport-specific anxiety is a better predictor of performance than generalized anxiety, and that this correlation is influenced by numerous individual factors such as locus of control, self-efficacy, and sport confidence (Felsten and Wilcox, 1992). Similarly, the correlation between anxiety and performance also takes on different trends depending on the type of sport practiced. For example, it has a significant negative impact in sports that require high levels of concentration and motor coordination (Felsten and Wilcox, 1992). Individual and contact sports are associated with high levels of cognitive and somatic anxiety, while sports involving individual scores based on judges' assessments predict high levels of cognitive anxiety (Martens et al., 1990). Self-confidence and self-efficacy are important variables related to sport performance (Robazza and Bortoli, 2007) since they increase perceived ability to emotion regulation and provides possibility for athlete to manage negative emotions more effectively (Besharat and Pourbohlool, 2011). High levels of self-confidence in athletes are associated with perceived useful ability (e.g., Martens et al., 1990; Robazza and Bortoli, 2007). It also moderates competitive anger symptoms (Hanton and Connaughton, 2002; Hanton et al., 2003), and facilitates coping resources for encountering anxiety (Jones and Hanton, 2001; Hanton and Connaughton, 2002; Robazza and Bortoli, 2007). Self-confidence before and during the match determines lower level of competitive anxiety and often correlates with better performance (Craft et al., 2003).

High stress levels can also generate burnout phenomena (Silva, 1990). Overwork during training is linked to a deterioration of immune functions, increased negative emotions and increased fatigue (Perna et al., 1998). Even regular training sessions can lead to negative consequences in case of conflicts, boredom, poor coping, or irregular work/rest patterns (Silva, 1990). Silva pointed out that repeated failure to cope with demands and discouragement related to continuous efforts that are ineffective can lead to burnout in sport, resulting in withdrawal from sport, low self-esteem, and loss of athletic identity (Silva, 1990). Furthermore, psychological stress is associated with increased levels of the stress hormone cortisol; in the case of chronic stress, athletes may be more frequently subject to injuries and illnesses caused by a lowered effectiveness of the immune system (Perna et al., 1998). By causing an excessive increase in concern about performance and the outcome of a competition, sub-optimal anxiety and the resulting increase in stress may also hinder the athlete in achieving an optimal state of flow (Kimiecik and Stein, 1992).

To cope with stressful situations in both sport and everyday life, it is necessary for athletes to master a wide repertoire of effective coping strategies to regulate suboptimal levels of anxiety (Lazarus, 2000; Schinke et al., 2012; Crocker et al., 2015; Nicholls et al., 2016a, 2016b). The scientific literature on the topic has demonstrated the effectiveness of some stress management programs in reducing anxiety and stress, with a positive effect on performance (Gould and Udry, 1994; Rumbold et al., 2020).

1.1.3 Coping and performance

Performance is the measurable result of a series of activities executed by the subject. In the sport domain it represents the result of a competition and how it took place, as it can be used to assess the ability of an athlete or team. The effects of coping strategies on performance have been extensively explored by the transactional model of stress (*Cognitive-motivational-relational theory,* CMRT; Lazarus, 1991, 1999). In the case of sports, athletes assess the subjective valence (primary appraisal) of the demands (internal and/or external) of a situation. The primary appraisal would determine whether these demands are negligible or relevant. The former would not require elaborate coping strategies, nor would they impact on the athlete's commitment, values, or goals. In contrast, when faced with demands that are deemed relevant (stressful), primary appraisal allows predictions to be made as to whether the athlete perceives the situation as an obstacle or threat (anticipated or experienced loss), or as a challenge (anticipated or experienced gain). Secondary appraisal allows one to assess the coping strategies available to cope with the situation, and how well the athlete feels he or she can govern the situation and the emotions related to it (Doron and Martinent, 2021). According to Nicholls et al. (2016a, 2016b), coping strategies would be differentiated into: *mastery coping*, i.e., strategies through which the athlete tries to suppress the stressor by attempting to take control over the stressful situation (e.g., problem-focused coping and task-oriented coping); *internal regulation coping*, through which the athlete tries to manage internal responses to stress (e.g., acceptance, emotion-focused coping); *goal withdrawal coping*, which refers to situations in which the athlete abandons all attempts to achieve his or her goal (e.g., disengagement-oriented coping). These strategies have a major impact on sport outcomes, improving or worsening performance, facilitating, or hindering the achievement of sport goals, and modifying emotional experiences (Nicholls and Polman, 2007; Crocker et al., 2015; Nicholls et al., 2016a, 2016b). Specifically, problem-focused coping strategies are found to correlate positively with performance and positive emotions, whereas disengagement-oriented and emotion-focused coping strategies have a negative association with performance and a positive association with negative emotions (Nicholls and Polman, 2007; Crocker et al., 2015; Nicholls et al., 2016a, 2016b).

According to the CMRT model, stress appraisal, coping behavior and emotions are dynamic psychological adaptation processes that enable us to adapt to and cope with the physical, psychological, and social changes we undergo throughout life (Lazarus, 1991, 1999; Nicolas et al., 2017). Stress would be the result of the interaction between individuals (cognitive appraisal and coping) and environmental factors. Consequently, the stress response also includes closely related physiological, cognitive, emotional, and behavioral components. Even though the CMRT assumes a strong interdependence between the psychological constructs at play (Lazarus, 1991, 1999), most studies have adopted approaches focusing on one or at most two constructs (Martinent and Nicolas, 2017; Doron and Martinent, 2021). More recently, a few studies have explored the relationship between stress appraisal, emotions, coping and sport activity outcomes (well-being or performance satisfaction), by structural equation modeling (Nicholls et al., 2012, 2014, 2016a,b; Britton et al., 2019; Thompson et al., 2020), but results are controversial. The relationships between these processes, and how their individual fluctuations are related to individual performance fluctuations require more process-centered and systemic approaches (Lazarus, 1991, 1999, 2000).

1.2 Stress management interventions

1.2.1 Stress assessment

Although the impact of stressors on well-being and health is widely recognized in the literature, empirical studies on the subject are scarce (Slavich and Shields, 2018). To date, there are no assessment tools that systematically evaluate the impact of stressor exposure (Slavich, 2019). Despite the diversification of stressors, the possibility that they emerge at different times and domains of life, and the interaction with socio-psychological characteristics, stress has been considered as a unitary construct (Epel et al., 2018). This results in a simplified view of the effects of stressor exposure (Epel et al., 2018).

The *Stress and Adversity Inventory* (STRAIN; Slavich and Shields, 2018) is often used to investigate the association between exposure to stressors and psychological, biological and well-being aspects. Its application in various fields has shown a strong correlation between stressors and depressive symptoms (e.g., Pegg et al., 2019), anxiety disorders (e.g., Slavich et al., 2019) and other physiological disorders (e.g., respiratory tract infections; Cazassa et al., 2020).

Most studies focusing on the effects of stress in sport have only considered certain types of stressors (e.g., related to competition, organization, or personal factors), rather than exploring the combined and cumulative effects of stressors on health (Fletcher et al., 2006). To assess their effects on athletes, such studies have made use of self-report checklists relating to traumatic or particularly significant events (e.g., Moore et al., 2018). Despite the advantage of being easily administered due to their brevity, checklists are limited to assessing the frequency of an extremely limited number of stressors, neglecting several dimensions that render the complexity of the phenomenon (Slavich, 2019).

To date, only one study has used STRAIN to assess correlations between stressors, mental health, and well-being in sports (McLoughlin et al., 2021). The results showed a correlation between chronic disorders and exposure to stressors with symptoms of anxiety, depression, and lower psychological well-being in elite athletes. Follow-up interviews revealed that cumulative exposure to stressors negatively impacts mental health and well-being because it: facilitates the sedimentation of non-adaptive coping strategies; increases susceptibility to future stressful experiences; and creates difficulties in interpersonal relationships (McLoughlin et al., 2021). However, the study did not assess the effect of sport-specific stressors, nor their impact on performance, and was limited to a sample of elite athletes.

McLoughlin et al. (2022) recently proposed an adaptation of the STRAIN to stress in sport (Sport SAM), analysing its usability, acceptability, validity, and test–retest reliability. The scale, which was administered to a sample of 395 sportsmen and women, showed a correlation with depressive and anxious symptoms as well as mental and physical disorders. Furthermore, it showed that the correlation between the severity of stress events (sports and non-sports) and health is mediated by trait stress appraisals (McLoughlin et al., 2022). In contrast to the self-report checklists used in previous studies, the Sport SAM considers the combined and cumulative effects of sporting and non-sporting stressful events and examines the effects of aspects related to the athlete's health, well-being and performance rather than focusing on only one of these aspects (Moore et al., 2018; Fletcher, 2019). However, some limitations of the study require further investigation. Firstly, the cross-sectional nature of the study design limits the possibility of determining causal relationships between the variables involved. Secondly, self-report measurements may be subject to cognitive bias and social desirability. Finally, the smallness of the sample and the average age (23 years) limit the generalisability of the results. Future research needs to enrich the promising results obtained through the Sport SAM through the implementation of longitudinal studies, the application of objective measures that are not susceptible to self-report biases (assessment tools that evaluate the effects of stressors on physiological markers, such as immune response, or trait stress appraisals, such as cardiovascular reactivity; Hase et al., 2019), and through the design of intervention protocols capable of lowering the effects of stress on health and performance.

In recent years, much attention is being paid to the analysis and evaluation of increasingly specific biomarkers, detectable by blood, urine and salivary tests and samples. In the current state of the art, the most closely monitored values concern dehydration (through sodium and creatinine analysis) to closely monitor weight and electrolyte changes in athletes, muscular tissue status, endocrine changes and cardiovascular changes through the evaluation and analysis of biomarkers such as cortisol, testosterone, DHEA and IGF-1 (Lee et al., 2017). Biomarkers relating to the state and risk of injuries, recovery after physical exertion and inflammation are further indicators worthy of attention.

1.2.2 Stress management

Starting from this theoretical framework, the importance of broadening the range of research-interventions to better understand which approaches are most functional for managing stress in the context of sports performance is widely recognized (Jones and Hardy, 1990; Anshel, 2005; Thomas et al., 2008; Rumbold et al., 2020). The studies to date that have proposed stress management interventions applied to sport have mostly been guided by the transactional stress process model. However, the declinations they have followed are different and have focused on one of several constructs at play, including: reduction of stressors, change in cognitive appraisals, reduction of negative emotions and increase in positive ones, and facilitation of effective behavioral coping strategies. The debate on the effectiveness of such treatments is still open. Optimizing an intervention should consider all components of the stress process, in their interactions and dynamic interdependence (Rumbold et al., 2020).

Among the most frequently used stress management treatment programs, *Stress Inoculation Training* (SIT; Meichenbaum and Deffenbacher, 1988; Meichenbaum, 2008) has achieved some positive outcomes in the field of sport (Long, 1984; Whitmarsh and Alderman, 1993; Holm et al., 1996). SIT involves three phases: conceptualisation, skill acquisition, and application. The skill acquisition phase, central to the program, consists of training cognitive strategies and makes use of techniques such as relaxation, controlled breathing, attention diversion and imagery, and positive self-talk (Kerr and Leith, 1993). Applications of SIT have proven effective in decreasing anxiety states, improving performance in studies (college athletes; Holm et al., 1996), and improving positive self-statements (Long, 1984). However, research has found no significant differences in performance compared to the control group.

The *Cognitive-Affective Stress Management Training* (SMT; Crocker et al., 1998) focuses on controlling emotional arousal through relaxation and cognitive techniques. Similarly to SIT, It consists of three phases, but adds emotional induction techniques in participants: after imagining stressful situations that increase anxiety levels, athletes are asked to adopt coping strategies (including self-talk and relaxation) to reduce anxiety (Crocker et al., 1988). Although the athletes reported fewer negative thoughts in response to videotaped stressors and improved service reception in volleyball training applications compared to the control group, no differences were found with the control group with respect to competitive state or trait anxiety (Crocker et al., 1998).

The *Cognitive-Behavioural Stress Management Intervention* (BCSM, Perna et al., 1998) has also been used in sport with promising results. The central component of the program is cognitive restructuring, a technique that involves identifying negative and dysfunctional thought patterns and learning to replace them with positive and self-affirming thoughts (Beck, 1984). Although with numerous variations in its applications, BCSM consists of a psycho-educational component (informing athletes about stress and its effects) and the use of cognitive (cognitive restructuring) and behavioral (muscle relaxation) techniques. In an application with college athletes, participants showed a decrease in negative emotions, fatigue, and stress hormone cortisol levels (Perna et al., 1998). Another study showed a decrease in anxiety and an increase in academic performance in the experimental group compared to the control group (Holm et al., 1996). However, these studies did not consider treatment outcomes on sports performance, and are limited to a population of student athletes, which invalidates their generalisability.

Systematic reviews that have attempted to summarize the outcomes of intervention programs in sport are few and dated. From the data collected from the 23 interventions on athletes included in their review, Greenspan and Feltz (1989) concluded that the most effective strategies to improve athletes' performance are relaxation-based strategies and cognitive restructuring programs. Martin et al. (2005) included 15 studies in their review, the majority of which focused on multi-modal cognitive-behavioral-based programs built on individual athletes. The authors report positive effects on performance in most of the studies considered. However, these reviews only considered interventions focused exclusively on improving performance, neglecting both intervention programs aimed at optimizing stress management in athletes and psychosocially oriented treatments aimed at improving the athlete's well-being in general (Miller and Kerr, 2002; Rumbold et al., 2020). Extending their review to include these criteria, Rumbold et al. (2020) considered 64 studies, which can be categorized into three different intervention types: *cognitive interventions*, in which the treatment consists of cognitive-behavioral therapy, coping, goal setting, hypnosis, imagery, rational-emotive therapy, and self-talk; *multimodal interventions*, which involve various combinations of: arousal control, attentional training, centering, cognitive control, cognitive and somatic relaxation training, concentration, COPE therapy, energizing, goal setting, hypnosis, imagery, meditation, motivation, pre-performance routines, positive thinking, self-talk, stress inoculation training, team building, thought stopping, and visuomotor behavior rehearsal; *alternative interventions*, which consist of anger awareness, applied relaxation, biofeedback, music interventions, personal goal management, and progressive relaxation training. From the scholars' analysis, multimodal treatments appear to be the most effective. However, the wide diversification in terms of intervention techniques adopted makes it difficult to understand which of these techniques combine best to produce effective outcomes. Furthermore, while interventions aimed at stress management have been shown to be effective in improving athletes' stress management in competitive sports, interventions aimed at also improving performance have shown fewer convincing outcomes. Finally, many studies have some methodological limitations that invalidate the generalisability of the results (i.e., small sample, no control group, and no manipulation check).

In general, the limitations of research in stress management to improve sports performance suggest some guidelines that need to be considered. First, individual differences in anxiety levels, performance and coping strategies must be considered within more personalized pathways (e.g., with accurate cognitive/somatic anxiety assessments). Such differences may affect the outcomes of treatments focused on single components of the stress process, which may be effective for some athletes and less effective for others. There is a need to move toward multimodal and multidimensional treatments that are guided by clear and well-defined theoretical models.

2 The PNEI proposal to stress management in sport

2.1 Stress from a PNEI perspective

In today's scientific landscape, a paradigm that seems to have much to offer to meet the above-mentioned needs, namely (1) the personalisation of treatments; (2) the multidimensionality of diagnostic processes and intervention models; (3) the integration of psychological and somatic components; is that of **Psychoneuroendocrinoimmunology** (PNEI; Ader, 1981), a discipline that has gained increasing consensus and credibility in the scientific community in recent decades.

Within this paradigm, which is inspired by the research on stress conducted in the middle of the last century by the Hungarian-born, naturalized Canadian physician and scientist Hans Selye, the knowledge acquired from endocrinology, immunology and neuroscience has gradually converged during the 20th century. This convergence gives PNEI a transversality that characterizes its approach to both research and treatment, aimed at studying the functioning of the organism in an integrated manner and the bidirectional relationships between psychological and biological systems.

Stress is one of the mechanisms that best lends itself to this integrated consideration and therefore constitutes one of the privileged fields of study of PNEI. The updated edition of the Handbook of Psychoneuroendocrinoimmunology (Bottaccioli and Bottaccioli, 2016) defines it as the fundamental way in which the organism, in its entirety, adapts to the physical and social environment. It is not one mechanism among others, which is activated only in the face of internal or external challenges that belong to the register of exceptionality, but rather a normal condition of life and a common phenomenon experienced in everyday life: not the exception to the rule, but the very rule of life (including sport activities).

Stress processes are the privileged mechanism through which the individual perceives, processes, and responds to the challenges of the environment, both physical and psychological. Such challenges are global since they invest the entire complexity of the human experience, as its activators cover a wide and transversal range of biological, psychological, and social factors. The stress response unfolds according to the same pattern (the stages and curve of stress discovered by Selye), but in the face of a wide range of different stressors: physical environmental factors (e.g., heat, noise, etc.), endogenous factors of physiological nature (e.g., reduced blood pressure, lowered immune defenses, etc.) or extraordinary and all-encompassing factors (e.g., infections, hemorrhages, etc.), pathological conditions of organic origin (e.g., chronic inflammation, serious pathologies, etc.), but also emotional and cognitive factors, thus linked to the individual's affective, relational and social life. Based on this unspecificity of the stress response, (Selye, 1974, 1977) theorized the existence of a 'general adaptation syndrome' (GAS), a vehicle for normal adaptation to the environment inside and outside the organism.

Today, research in this field has confirmed and deepened these insights, and PNEI, in particular, has contributed to innovating our knowledge in three respects: (1) the nature and functioning of the psychobiological appraisals that govern the stress response (with the elaboration of the notion of **allostasis**); (2) the centrality of **interoception** mechanisms which lies beneath stress regulation processes; (3) the role of the environment as a moderator and activator of the stress response and its impacts on the organism (lifestyle research related to **epigenetics**). From the intersection of these three aspects has emerged an innovative and powerful concept of stress from both a diagnostic and therapeutic point of view, capable of firmly embedding the psychological components of stress (appraisals and coping styles, as they were already explored, among others, by the Lazarus' transactional model) in the physical and biological realm of the body.

2.1.1 Allostasis and psychobiological regulation

Considering this new set of knowledge, the stress system is indeed revealed to be an integral part of the ever active and largely unconscious interoceptive network (brain's *intrinsic* activity) that issues predictions about the body, tests the resulting simulations against sensory input from the body, and updates your brain's model of the body in the world (Seth, 2015; Barrett, 2017). It is a complex and sophisticated predictive system of adaptation to the environment, which processes predictions about the body's *internal milieu*, correlating it to the continuous variations and changes in the external environment, to ensure that the organism adapts as well as possible (*fitness*) to its context. And this also by way of derogation, if necessary and within a certain margin of tolerance, from the homeostatic parameters of bodily physiology. This is an important extension of the traditional physiological conception, more closely anchored to the idea of homeostasis as the restoration of equilibrium prior to the stress condition, which opens to a more elastic and flexible functioning with respect to environmental variations, capable of renegotiating extra-homeostatic conditions of adaptation named as **allostasis** (Sterling and Eyer, 1988).

The predictive and dynamic nature of allostatic mechanisms requires a more complex neurobiological direction of stress mechanisms than that of purely homeostatic systems, calling into play the brain as a whole, with the involvement of vast cortical and subcortical neural networks of control and management including, in particular, the Salience Network and the Default Mode Network (Bottaccioli and Bottaccioli, 2016; Barrett, 2017; Minelli, 2020), in functional communication with deep subcortical limbic centers (especially amygdala and hypothalamus). In the PNEI model, the mind is thus at the center of stress processes, as the governing pole of appraisals and allostatic evaluations that regulate the search for a predictive and dynamic balance with the environment. An aspect that, as we shall see, also has relevant implications on the side of stress-related treatments and therapeutic interventions, which are also applicable to the sport domain.

2.1.2 Distress and allostatic load

Allostasis represents a 'biological' possibility for the organism, an option that can be exercised under certain conditions and within certain limits. On the one hand, it is a valuable resource for the individual since it allows an adaptation that is no longer merely reactive, but predictive and dynamic to the environment and more flexible than pure homeostatic functioning. On the other hand, by deviating from internal homeostasis, it always entails a physiological 'cost' for the organism called 'allostatic load'. This load takes the form of an increase in psychobiological arousal levels and states of hypervigilance and generalized psychobiological tension in the organism.

From a PNEI perspective, therefore, three different cases are distinguished in relation to stress:

- **eustress**: activation of the stress system in which the organism overcomes the stressor(s) without exceeding permanently its homeostatic parameters. Eustress represents a positive and life-sustaining condition in which the organism does not pay any particular physiological cost at the level of its biological systems. The stress response mobilizes the energetical resources of the organism only for a limited period of time, after which the initial condition, prior to the stressful activation, is restored.
- **distress**: activation of the stress system in which the stressor(s) persists over time, and tends to chronicize the stress condition. In order to cope with this prolonged activation, the organism must deviate from its homeostasis and negotiate a different balance with the environment. This implies to pay necessarily a physiological cost of adaptation (the *allostatic load*).
- **burn-out**: a pathological condition of depletion/exhaustion of the body's adaptive resources, brought about by the progressive accumulation of allostatic load that, beyond a certain threshold and under certain conditions, comes to render the individual unable to tolerate the stress levels of his or her environment. Burn-out, therefore, is only the last "station" of distress, the end point of a condition that gets progressively out of control; a veritable syndrome that requires medical and psychological interventions.

According to this distinction, it is therefore important to emphasize that distress does not represent a pathological condition *per se* but a possibility inherent in the degree of freedom that allostasis offers to our biological constitution. However, the accumulation of these deviations over time, with the related hyperactivation of the stress axes (mainly the HPA axis), may lead to chronic stress, to pathologize the organism's state of health and favor the onset of numerous diseases, remain as a risk.

An increase in distress levels is closely associated with a significant increase in cortisol levels. If perpetuated over time (in a chronic sense), it leads to a progressive weakening of the athlete's immune system and subsequent fatigability, chronic stress, and health problems (Palacios Le Blé et al., 2015). It is therefore important to monitor the levels of distress associated with different allostatic loads to prevent them from exceeding the body's tolerance threshold.

But how and according to which methodology is such detection possible? Conventional biological approaches in stress management generally focus on the detection of specific parameters that are particularly significant for the stress condition. The focus is on individual biomarkers and countermeasures are triggered when these parameters reach levels of clinical significance, considered as conventional cut-points. Although these biomarkers are indeed linked to the stress reaction, several recent reviews have shown that this methodology shows little predictive capacity with respect to the onset of burn-out or pathological distress conditions (i.e., Danhof-Pont et al., 2011). The limitation would thus be represented not by the considered indicators in themselves, but by their separate and isolated evaluation. This approach is unable to account for the non-linear effects on physiological systems that stress exerts on the organism. Chronic stress, in fact, entails a series of impacts that accumulate over time, depending on the prolonged exposure to stressful situations and to the changes in the internal and external body's conditions. To make the stress condition objective from a biological point of view, therefore, a broader and more comprehensive evaluation should be put in place. It is a question of constructing an integrated and multi-systemic index that is oriented toward defining the overall picture of the dysfunctions and imbalances that occur at the expense of the main physiological systems that regulate stress. As Minelli and De Bellis (2014) note, such an index, which for the following we will refer to as the **aggregate index of allostatic load,** incorporates information relating to a multiplicity of physiological systems that are involved in a functionally interconnected manner in allostatic processes; for this reason it is able to more fully reflect the cumulative effects of allostatic load on our organism (Juster et al., 2010). This is true in all stressful conditions, including the sport activity. At a professional level, in fact, sport is a privileged allostatic exercise and concerns athletes very closely: it shifts the individual's psycho-biological limits and tolerance thresholds further and further through constant physical and mental training. Depending on the goals that the athlete intends to achieve, the prolonged and intense exercise that he or she undergoes daily determines significant deviations from the basal activity of his or her body, with modifications to both body and mind. Knowing the opportunities and risks of allostatic loading, learning how to manage it and contain the inevitable wear and tear effects, is therefore particularly appropriate for those individuals who, like sports athletes, subject their bodies to significant and constant physical and mental stressors.

2.1.3 Epigenetics and lifestyles

The third contribution that PNEI offers to stress management models is the important focus on the relationship between lifestyle and eustress/distress. In the light of the most recent scientific findings on epigenetics, in fact, it becomes much clearer how, how much and through which biological mechanisms the environment comes to influence the development of the organism and the setting of the stress system itself. Many steps forward have been taken in the direction of a more complete understanding of the complex relationship between genes and environment, so much so that today it is no longer possible to consider the genome as a steering center that gives instructions to the organism (as the fathers of molecular genetics, Crick and Watson, proposed to consider it), but rather as an adaptive device that responds to environmental demands by regulating gene expression (Bottaccioli and Bottaccioli, 2023). Epigenetic research has revealed the existence of a kind of genomic plasticity that brings reversible and irreversible changes to the organism (epigenetic signatures) which, in some cases, can even become trans-generational hereditary traits.

Thanks to epigenetic mechanisms, therefore, the organism modifies itself throughout its existence, in a continuous and constant exchange with the environment and in particular with certain particularly influential factors, including (a) polluting and toxic factors ('endocrine disruptors'), (b) the diet which, depending on the substances contained in the food, can have inflammatory or anti-inflammatory effects (e.g., excessively refined fats or sugars activate the transcription factor NF-kB, promoter of genes involved in the production of inflammatory molecules; resveratrol, curcumin, butyrate and other short-chain fatty acids work in the opposite direction); (c) physical exercise, which has proven positive effects and reduces the body's inflammation levels; (d) emotional stress, which can deeply affect the functioning of the stress system itself.

Research in this field has allowed us to recognize the influence of all these factors on the physiology of the stress system, switching phenomena of physical and psychosocial nature, as well as our lifestyle habits, into stable changes in the organism. This awareness is remarkable in professional sports, where individuals are subject to high emotional and psychological stress loads, and where nutrition and exercise are central dimensions.

2.2 Potential developments of the PNEI approach in sport

In the light of these considerations, integrating this knowledge into the stress management models currently in the sport domain would be worthwhile. A PNEI model should be applied in terms of diagnostic tools, prevention interventions and treatment models for athletes both in relation to how they perceive and manage stress, and to promote an improvement in their performance under the banner of sustainability and health. Such integration opens the field to highly personalized work, since everyone is a 'measure of themselves' in stress, especially when the psychological dynamics of allostatic appraisals, individual habits and lifestyles, and the richness of the person's socio-emotional experience are considered. The PNEI paradigm, in this sense, has a strong individualizing vocation and enables the development of assessment settings and treatment models characterized by much more personalized pathways.

Any intervention that wants to affect distress, in fact, must work on the individual stress management modes that people deploy to cope with life's challenges. Such strategies are structured over time through allostatic appraisals and translated into consolidated stress management models and styles which are linked, on the one hand, to *recurring psychobiological patterns* (the cascade of bodily phenomena that accompanies the stress reaction); on the other hand, to the *coping strategies* adopted with a certain frequency. These allostatic, predictive patterns of adaptation to the environment are built up over time and become part of the largely unconscious baggage of individuals, often in the form of behavioral, cognitive, and emotional automatisms that guide personal and professional practices, not always in a functional manner. To become the object of treatment, therefore, these mechanisms require specific work to emerge and raise awareness. A distress intervention aimed at addressing these cores must focus on personal 'self-awareness', to favor the perception of experienced distress levels, the identification of consolidated stress management patterns and related coping strategies, as well as the quality of one's lifestyle.

The main areas of intervention on which a distress intervention model developed from a PNEI perspective should primarily work, through the lever of self-awareness are, in our opinion, four:

1. *Interoceptive body listening*: to stimulate athletes to become more aware of the interoceptive aspects of their own psycho-biological functioning, especially with regard to the activation of stress axes;
2. *Knowledge of one's own stress management styles,* i.e., the automatisms, coping strategies and recurring defense mechanisms that are associated with allostatic appraisals;
3. *Knowledge and reflection on lifestyles* (promoting reflection on eating habits, exercise and other variables, both physical and psychosocial), that are central to individual allostatic load from an epigenetic perspective;
4. *Activation of the* person's *support network*, i.e., all those internal and external factors that can predispose or conversely mitigate the stress reaction (among which social support plays a key role)

The work on these dimensions, in line with the theoretical-clinical paradigm of the PNEI, is carried out from a multidimensional perspective, with the elaboration and application of a mix of diagnostic (i.e., assessment) and intervention tools that explore both the psychological dimension of stress management and the psycho-educational and psycho-physical dimension, according to a truly integrated approach to the athlete's health and psychophysical well-being.

2.3 An integrated multidisciplinary approach

Based on the aspects highlighted in the preceding paragraphs, our theoretical-methodological proposal consists of the definition of an integrated protocol of psycho-biological assessment and intervention on the allostatic load and on the levels of distress/eustress detectable in the sport environment, in relation to the person's health/well-being condition and the impact of this condition on the quality of sport performance.

This paradigm has the potential to integrate aspects of replicability with customisation requirements that are linked to the context in which the athlete operates and to her/his individual needs and specificities.

Lastly, its multidisciplinary nature requires close cooperation between different professional figures, such as psychologist (mainly, health psychologist, and sport psychologist with experience in mental coaching), nutritionist, osteopath, and physiotherapist, as well as biologists, physicians and kinesiologists, both in planning and in implementation and monitoring at all stages.

The intervention protocol, mainly addressed to elite athletes, is in its planning phase. The following are to be considered as the main drivers for its implementation.

2.3.1 Methodology of intervention

The protocol consists of three phases: assessment, treatment, and monitoring.

- The **assessment** consists of profiling the athlete, aiming at reconstructing the global picture of his or her psychophysical condition, through the drawing up of a medical record containing the main information concerning the athlete's psycho-emotional, physical, and nutritional spheres and lifestyle habits.
- The **treatment** consists of an intervention program that includes actions aimed at working on both the psychological aspects related to stress management and the psycho-educational components linked to lifestyle habits, as these are salient aspects of the athlete's mental and physical health and well-being.
- **Monitoring** consists of the quali-quantitative assessment, during the treatment, at its end, and in the follow-up phase, of the athlete's progress, which will be evaluated and followed up, with a view to improving and/or maintaining an optimal state of health, as well as with a view to performance and injury prevention.

2.3.1.1 Assessment

The protocol starts with taking charge of the athlete and drawing up a medical record. The athlete is jointly assessed by an interdisciplinary team composed of health and mental wellbeing professionals (health psychologist, and sport psychologist with experience in mental coaching), health and physical and bodily wellbeing professionals (doctor, physiotherapist, osteopath, kinesiologist, nutritionist, etc.), laboratory experts to support the clinical analyses and biological assessments carried out, assisted by the staff that usually follows the athlete (coach, athletic trainer, etc.).

Psychologist draws up a profile of the player, assessing the following aspects:

- subjectively perceived stress load and detectable levels of psychological well-being/illness;
- the ability to listen and decode stress-related interoceptive processes and the cascade of psychobiological phenomena associated with the allostatic response;
- habitual stress management patterns and related coping strategies adopted in one's own experience;
- established lifestyles and awareness of their impacts on stress response and levels of psychophysical well-being;
- the quality of the perceived social support network (relationship with the coach/athletic trainer/staff, relationship with the team, any perceived pressures in family and community contexts).

This evaluation requires the adoption of quali-quantitative analysis and survey tools, using batteries of reference tests/questionnaires (e.g., Strain and Sport SAM), interviews, self-reports, etc.

In addition to the usual medical assessments of the athlete's general health condition and physical performance, the assessment protocol includes a specific activity to assess the allostatic load and stress levels detectable in the body. To this end, with the support of specialized biologists and laboratory technicians, a battery of tests and laboratory analyses is carried out, with the detection of the main salivary and blood biomarkers of stress, such as cortisol, DHEA, testosterone, oxytocin, and melatonin (administered according to the seasonal training and performance load). The detection of biomarkers is fundamental in our methodological proposal for the investigation of the main biological systems, such as neuroendocrine, cardiovascular, metabolic, immune-inflammatory and redox state. In line with PNEI approach, these indicators will not be considered in a single and unrelated manner, but rather through an integrated assessment aimed at determining the aggregate allostatic load index (Juster et al., 2010; Minelli and De Bellis, 2014), strongly indicative of the athlete's instant stressful conditions.

To have an overall and global picture of the psychophysical condition and lifestyle, in addition to the psychological and biological assessment, the athlete is also assessed from three other points of view:

- by the nutritionist biologist, in relation to one's eating habits and preferences, possible intolerances, allergies and sensitivities: objective measurement using BIA (bioimpedance analysis, for detecting lean mass, fat mass, water percentage and fat distribution, as well as calculation of basal metabolism). Depending on the anamnesis, further investigations may be recommended for the detection of any paraphysiological (such as dysbiosis) or pathological conditions.
- by a physiotherapist, orthopaedist, and osteopath to detect any dysfunctions and functional deficits, so as to understand the propensity to risk musculoskeletal injuries. This joint evaluation will be fundamental for the identification of postural disorders and for the detection and identification of possible painful conditions, limiting performance and/or sources of distress. The kinesiologist will then proceed with the integration of postural assessment and kinematic analysis of the main movements involved, such as analysis and measurement of the ROM (range of motion) and measurement of strength tests with a dynamometer;
- by consultants specialized in the assessment of sleep quality and sleep hygiene through specific dedicated questionnaires, to make the necessary improvements and corrections (e.g., ESS - Epworth Sleepiness scale, Johns, 1991; PSQI - Pittsburgh Sleep Quality Index, Buysse et al., 1989; SWAI - Sleep/Wake Activity Inventory, Rosenthal et al., 1993). The close connections between adequate quality of sleep and athletic performance are well highlighted by recent scientific literature.

From the integration of these evaluations and based on threshold values preliminarily identified by the research team, the population of athletes will be divided into 3 groups:

Optimum profile (green): the athlete appears to be in excellent psycho-physical condition and perfectly fit. No criticalities or imbalances emerge in relation to the global assessment of the psychophysical condition and lifestyles.

Average profile (yellow): the athlete appears to be in good psycho-physical condition and moderately fit. Minor imbalances emerge in relation to the global assessment of the psychophysical condition and lifestyles.

Critical profile (red): the athlete appears to be in poor psycho-physical condition and low performance. Extensive and widespread deficits emerge in relation to the global assessment of the psychophysical condition and lifestyles.

2.3.1.2 Treatment

The treatment involves the application of a series of methods that work on the different aspects assessed during the assessment (psychological, physical, biological, stress management, lifestyle, etc.) to promote a general improvement in the athlete's condition of life, health, and psychophysical well-being. A non-exhaustive list of tools that can be implemented within the treatment protocol includes:

- Breathing and body relaxation techniques to de-stress and reduce anxiety and tension levels (e.g., diaphragmatic breathing, autogenic training, biofeedback, meditation, etc.);
- listening and interoceptive awareness techniques to improve the athlete's individual knowledge and sensitivity to his or her body and the cascade of psycho-biological phenomena related to the stress response (e.g., body scan, mindfulness techniques, PNEI-Med method, etc.);
- techniques for restructuring coping strategies in its different declinations (emotional, cognitive, behavioral, and social support coping) to promote the adoption of more functional and adaptive coping styles (e.g., mental imagery, stress balancing, self-talk, metacognitive and reflective tools, etc.)
- psycho-educational training for improving lifestyles oriented in particular on the dimensions of nutrition and sleep (e.g., lifestyle diary and its monitoring protocol; nutrition re-education interventions, sleep hygiene practices, etc.);
- treatments to improve the body's general physical, inflammatory and musculoskeletal condition (physiotherapy and osteopathic treatments, acupuncture).

Based on the assessment and psychobiological profiling process, the team has at its disposal a wide range of qualitative and quantitative data useful for the strategic planning of the pathway to support the athlete's psychophysical condition. In relation to the results of the profiling:

Intervention 1 - Optimal profile: periodic ongoing monitoring should be scheduled (depending on the specifics of the sport practiced and seasonality) of the biological readings related to the individual's allostatic load, to verify any deviations from the optimal condition detected. Treatment will focus primarily on interventions of a preventive nature, with the application of stress management techniques, physiotherapy and osteopathic maintenance sessions, possible meditation and breathing techniques as needed and depending on the workload.

Intervention 2 - Medium profile: a specific treatment protocol will be drawn up to work on the most relevant aspects of imbalance that emerged during the assessment of the athlete's psychophysical condition. It is fundamental to foresee a periodic ongoing monitoring of the progress made, with ongoing evaluations for the eventual reconsideration and reshaping of the treatment plan. In areas where no imbalances emerge, periodic monitoring of the biological readings linked to the individual's allostatic load (depending on the specifics of the sport practiced and seasonality) is likewise planned.

Intervention 3 - Critical profile: a specific treatment protocol will be drawn up to work on the critical aspects that emerged during the assessment of the athlete's psychophysical condition. Priority is given to the recovery of the psychophysical and metabolic condition and the prevention of injuries and relapses through a highly specific and customized approach. Compared to the type 2 intervention, therefore, a more intensive and transversal work plan is envisaged, aimed at comprehensively addressing the distress condition and insisting on all salient areas of psychophysical health and well-being. The treatment pathway will be accompanied by more frequent and wide-ranging ongoing monitoring of the progress made, with assessments for possible reconsideration and remodeling of the treatment plan. Periodic ongoing monitoring of biological readings related to the individual's allostatic load (depending on the specifics of the sport practiced and seasonality) is also planned.

2.3.1.3 Monitoring

During the treatment phase, at regular intervals or on the occasion of particular events (e.g., traumatisms, significant reduction in performance, increase in perceived levels of distress and malaise, illnesses and/or systemic pathologies) and depending on the periodisation of the training and performance load, the biomarker measurements carried out during the assessment phase will be replicated, in order to objectivise the trend of the subject's psycho-biological condition. Continuous monitoring allows a direct comparison with previous conditions and the possibility of anticipating and preventing certain conditions that could become dysfunctional or limiting for the athlete.

At the end of the treatment, a psychological re-test phase is envisaged through the administration of the assessment tools already used in the profiling phase (e.g., STRAIN and Sport SAM), aimed at assessing the results of the treatment also from a psychological point of view (e.g., stress management, coping strategies and psychological well-being) for the overall assessment of the pathway and the possible planning of follow-up moments.

During the different phases of the path, the continuous sharing of data and information also with the team itself (teammates, coaches, trainers, managers, etc.) is crucial to encourage personal and common objectives and for full sharing of operational models, in favor of a peaceful environment and mutual trust. The athlete, once he has shared the path with the whole team, will find it increasingly easier to discuss his perceived state of stress and will be more compliant in choosing the most suitable treatment, with clear responsiveness in the medium-long term.

3 Conclusion

In this article, we have developed a theoretical proposal for the integration of a psycho-biological assessment protocol and a related intervention plan, which is inspired by the appraisal and stress management methodologies of Psychoneuroendocrinoimmunology.

This integration is necessary and desirable to strengthen certain aspects of stress management and performance empowerment with respect to the key dimensions identified in the specialist and reference literature in the field of sport.

In particular, the integration with the PNEI-inspired methodologies make it possible to define a solid and valid diagnostic and intervention model on a theoretical, methodological, and scientific level, which is therefore easily replicable and adaptable in different sports contexts (group and individual), at different professional levels, with respect to the many types of activities practiced, and in relation to the specific psychophysical conditions of each athlete. This replicability is supported and favored by the multidimensional and multidisciplinary nature of the PNEI paradigm, which strives to combine, in the same model, scientific knowledge and evidence from a wide range of medical, psychological, health care and physical and bodily well-being disciplines. The integration of psychological and somatic components is, moreover, one of the main valuable aspects of the PNEI paradigm's explanatory model of stress functioning; an aspect that we also wished to apply in a sports context.

This declination has taken into strong consideration the syndromic nature of stress, which refers to a multi-componential constellation of clues and symptoms belonging to a plurality of dimensions that concern both the more physical-biological aspects of the organism and performance evaluation, and the more properly psychological, social and relational aspects. This makes the condition of stress extremely pervasive in relation to the person's life. High levels of allostatic load and distress, in fact, can have a very relevant and all-round impact on the health and well-being of athletes. For this reason, the protocol also emphasizes lifestyle components, which can profoundly influence the development of the organism and the setting of the stress system itself, in line with the current knowledge of epigenetics.

Finally, this constellation is also shown to have a strong individual variability: it does not manifest itself in the same way for everyone and in all sports, it can also shift significantly over time, depending on the different living conditions of the person and their context. It is therefore essential that stress management protocols, in addition to being rigorous and scientifically reliable, as well as replicable, should also be able to modulate and adapt to the specific characteristics of the type of sport, the type of context, the individual uniqueness of the athlete, and the factors linked to the contingency of the specific moment/phase. Our proposal, in this sense, provides for a strong customisation and flexibility of the diagnostic, treatment and monitoring processes, to provide a detailed and global picture of the athlete's physical and psychological condition and its possible fluctuations over time.

In the light of these considerations, it is possible to hypothesize a methodology of approach in a PNEI key that responds to the need to manage the allostatic load and the assessment of athletes' psycho-biological distress levels, through specific, measurable, and integrated interventions, as personalized as possible. This approach, in addition to the already envisaged psycho-physical benefits in the short and medium term, could bring about an improvement in the overall management of the athlete, with respect to his or her psycho-physical health and well-being, performance and quality of life in general.

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GT: Conceptualization, Methodology, Writing – original draft. VZ: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. AN: Conceptualization, Writing – original draft.

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Evolution of attack in handball when playing 7 vs. 6 with empty goal between 2020 and 2023: coaches' perception vs. observational results

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Introduction: Recently, several studies on the 7 vs. 6 "empty goal" (EG) in handball have produced different and even contradictory results. The aim of the present study was to investigate the behavior of teams and players in the 7 vs. 6 EG attack in the European (Euro) and World Championships (WCh) between 2020 and 2023 and characterize the coaches' perceptions.
Methods: A mixed-methods approach was used, consisting of the following: (i) an observational methodology and instrument developed and validated to collect observational data on player and team behavior; and (ii) a developed and validated questionnaire to coaches on their perceptions of the 7 vs. 6 game. Observational data were collected during the Euro 2020 and 2022 games ($n = 62$) and the WCh 2021 and 2023 games ($n = 70$). A total of 132 games and 391 situations of 7 vs. 6 attacking sequences were observed. In total, 156 coaches participated (146 men), with a mean age 42.33 ± 11.87 years, 19 nationalities, and with 12.77 ± 9.45 years of experience.
Results and discussion: The choice of 7 vs. 6 offensive play was mostly made in the second half (>73%). The effectiveness of 7 vs. 6 offensive sequences was higher in the top six teams than in the team's ranked 7th to 12th (Euro 2020 51.6%–50.0%; WCh 2021 52.0%–50.0%; Euro 2022 53.1%–41.7%; WCh 2023 50.0%–43.8%). Some patterns of association were found ($p < 0.05$ and with values >±1.96): (i) scoring a goal with a breakthrough shot was significantly associated with the effectiveness of the 7 vs. 6 attack (Euro 2020 2.61; WCh 2021 2.87; Euro 2022 2.68; WCh 2023 2.32); (ii) teams in the top six significantly used 7 vs. 6 when they were winning (Euro 2020 2.17; WCh 2021 3.52; Euro 2022 5.88; WCh 2023 2.54); and (iii) teams in the bottom six used it when they were losing by at least four goals (Euro 2020 7.56; Euro 2022 6.64; WCh 2023 4.37) or when they were winning by four goals or more (WCh 2021 2.58). Coaches that agree with the possibility of playing 7 vs. 6 (74.4%), rarely or never do so (55.6%) because it brings little or no advantage (52.6%). The results of the analysis confirmed the perception of the coaches, the low use of 7 vs. 6, the low advantage associated with it, and the influence of the result and the moment of the game on its use.

KEYWORDS
men's handball, mixed-methods, observational methodology, polar coordinate, questionnaire, attack with empty goal, coaches' perception

1 Introduction

Team sports, such as handball, involve complexity, opposition, and cooperation. They are characterized as being interactive, with players interacting with each other, both teammates and opponents, and with context, whether at the location of the game, in the area of the field where the action takes place, in the elapsed game time, in the partial result, or in the numerical relationship (1–3). Players' behaviors are generally emergent, deriving from individual characteristics, as well as from the possibilities that the context offers and from the characteristics of the tasks performed by the players (4–7). Handball is a complex system, as defined by Balagué et al. (8), in which strategic tactical behavior is crucial (9–12) and performance is the result of interaction between different factors and variables, including the numerical relationship. Currently, handball games with different numerical relations are frequent, due to the characteristics of the rules of the game—with their progressive penalties, and the possibility of players being punished with 2-min exclusions, with disqualification due to accumulation of exclusions and with direct disqualification (3). These authors stated that, having different symmetrical and asymmetrical numerical relationship in the number of players, is clearly a characteristic of the current handball game, which has been increased in recent competitions (13, 14), especially after the changes of the rules in 2016, with the possibility of playing in attack with an empty goal (EG) (13). The most common relationships are still 6 vs. 6, 6 vs. 5, 5 vs. 6, and 5 vs. 5 with goalkeepers at goal, but since the change of the goalkeeper rule, the 7 vs. 6 and 6 vs. 6 game situations with an EG are becoming more common and have attracted the attention of researchers with some published studies, with 7 vs. 6 being the situation that has focused the most attention. In the last 7 years, several studies have been carried out on the 7 vs. 6 with an "empty goal" (7 vs. 6 EG) game. The results obtained, varied and even contradictory among them, are in line with the controversy that arose when the regulatory change allowing 7 vs. 6 situations was approved (7, 15–24). Regarding 7 vs. 6 EG, it is important to note that the majority of some studies found and analyzed observational procedures; regarding 7 vs. 6 EG, it is important to note that most of the studies found follow observational procedures. Only a few studies analysed the opinion and perception of the coaches (22, 23, 25–29) and only one study was found that considers the opinion of the players (24). As observed by Korte and Lames (30), with this new rule of attacking with an "empty goal," different attacking formations have increasingly occurred, such as seven attacking players (with two pivots or with one pivot) vs. six defenders. This reality was complemented by Maroja et al. (18), who observed that losing teams tend to use this strategy more than winning teams (9.7% and 3.9%, respectively) during the play-off stage at the 2017 Women's Handball World Championship (WCh). The use of the rule to attack with seven players and an empty goal generated controversy within elite handball, discussing the risk assumed by the teams that opt for this tactical option (25, 26), in concordance with Antón (31). In the research carried out by Bonjour et al. (32), with a sample made up of 571 attack sequences with an empty goal, referring to 50 games of the 2018–2019 European Handball Federation (EHF) Women's Champions League, the results showed that the teams managed to significantly recover defensively, in an adequate manner, and organize their defense. However, they recorded a considerable number of direct goal-to-goal shots against (15.7%), with an effectiveness level of 57%. The authors concluded that teams, when attacking with an EG, take on a significant risk of conceding a goal quickly if they do not score a goal. However, Gümüş and Gencoglu (17), when studying the effects of the goalkeeper substitution rule as a new strategy in handball, concluded that the teams that used this strategy, despite not having greater efficiency in attack, did not have negative consequences nor did they have an increase in risk when playing 7 vs. 6 EG. Krahenbühl et al. (25, 26) pointed out these main conclusions: coaches considered there were no significant strategic changes in handball neither in attack nor in defense, and that the additional court player was used to maintain the numerical equality in the attack in situations of exclusion and, in some specific cases, aimed at numerical superiority in final and decisive moments of matches. Prudente et al. (27) studied the coaches' perception on playing 7 vs. 6 EG and stated that the majority (65.8%) of Portuguese coaches considers that game time influences the use of the "7 vs. 6 EG" strategy, and 92.2% of them stated that this use occurs in the final moments of the game. Coaches (74.7%) have the perception that the result influences the use of 7 vs. 6 EG, with 90.7% considering that being behind in the score positively influences its use. Sousa et al. (23), in their study about the Portuguese coaches' perception about play 7 vs. 6 EG, concludes that most coaches (86.3%) agree with the possibility of using this strategy. Most respondents (70.9%) do not think that the game is mischaracterized, but only 13% always or often use this possibility and three-quarters do not agree with the elimination of the rule. Antón (33) stated that the rule is strategically used as often as in every game of a national team's tournament, such as the Portugal Men's National Team at the 2020 Men's EHF Euro, where Portugal even played a complete match using this tactic. To deepen our knowledge of the topic and its implications for the current handball game, we decided to study the behaviors of teams and players, in a 7 vs. 6 situation with an empty goal, over the last 4 years of high-level international competitions, at the Men's European Championship (Euro) and Men's WCh, more precisely between 2020 and 2023, crossing the observation results with the coaches' perceptions about playing 7 vs. 6 EG.

2 Material and methods

The study uses a double methodology: (i) observational methodology, using an idiographic (I)/multidimensional (M)/follow-up (F) observational design; idiographic due to the fact that all the sequences 7 vs. 6 were observed as a unit in the same competition; multidimensional (M) in that several response levels were studied; and follow-up (F) as several games played in the same championship were observed; having then data located in the first quadrant and type 1 data (34, 35). Data from games were collected using an *ad hoc* observation instrument built and validated for this purpose; (ii) the application of a questionnaire on the coaches' perception of this new rule and its influence on the game, which was constructed and validated using the Delphi method. Regarding the observational instrument, the one used by Prudente et al. (7), in their study of the use of 7 vs. 6 EG during the 2020 EHF Men's Euro, was applied to collect data from games. Moreover, coaches' opinion and perception were registered via a questionnaire compiled using Google Forms. Given its characteristics, high scientific rigor, flexibility, and the allowance of an objective study of spontaneous behavior in natural settings, the observational methodology has become one of the preferred methods in scientific research in sport and team games, particularly in handball, which has been using it in recent decades (36, 37). Mixed-methods studies are being increasingly applied to a diversity of fields and have enormous potential in the field of sport and physical activity (37, 38). In the present study, a mixed-methods approach was used. Through systematic observation, data from the behavior of players and teams in a competitive environment were registered. With the qualitative data obtained, a quantitative analysis was then carried out, using the lag sequential analysis and polar coordinate analysis techniques. Through a survey of coaches, data on their perception regarding the game 7 vs. 6 EG were obtained, allowing the cross-referencing of information obtained with the observational data, completing the information and interpretation of the data.

2.1 Sample

2.1.1 Observational sample

The observational sample consisted of the total number of offensive sequences carried out while playing 7 vs. 6 EG, in the positional attack ($n = 391$), during the 132 games played by teams ranked 1–12 at 2020–2022 EHF Men's Euro ($n = 62$) and 2021–2023 IHF Men's World Championship ($n = 70$). All the sequences registered occurred in numerical superiority 7 vs. 6 with the team in possession of the ball playing without a goalkeeper at goal (EG), starting and ending with the previous numerical asymmetry mentioned. Table 1 presents the distributions of the offensive sequences in the four tournaments.

2.1.2 Instrument

The instrument used to collect data was a mixed *ad hoc* instrument consisting of a field format with category systems (7), with 11 criteria and 77 categories: (1) teams, according to final ranking at the competition (T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12); (2) game time, 10-min parts of the first and second halves until 50 min (A1, A2, A3, B1, B2), 5-min parts of the last 10 min of the second half (B3, B4) plus extra time (P1, P2, P3, P4); (3) the partial score (E, V1, V2, V3, V4, D1, D2, D3, D4); (4) defensive system (6:0, 5:1, 3:2:1, 3:3, 4:2, 5 + 1, 4 + 2, HxH); (5) offensive organization, with one or two pivots (1Pv, 2Pv); (6) tactical means, individual means, and group means (Ind, Group); (7) shot, from 9 m (RIL), wing shot (RPt), pivot shot (RPv), breakthrough shot (RPn), no shot (SR); (8) attack result: goal (G), no goal (NG), 7 meters with goal, (7MG), 7 meters no goal (7MNG), no shot by technical fault (SFFt), no shot by opponent action (SFAa); (9) the shot zone of the offensive sequence—a field map was designed with 10 zones: 9 zones on the offensive side (left/right wing, left/central/right zones from 6 to 9 m; left/central/right zones from 9 to 15 m; left/central/right zones from 15 to 20 m) and 1 zone on the defensive side; (10) opponent response: goal to goal attempt (GD), direct fast break (CAD), sustained fast break (CAA), throw-off (Rep), fast attack (AR), organized attack (AO), no response (NE); and (11) opponent response result: goal (Golo), no goal (Ngolo), no goal with penalty (NGcP), no action (SA).

2.1.3 Procedures

Data were observed and recorded using Lince software v.1.2.1 (39). SDIS-GSEQ v. 5.1.23 (40) and Hoisan v. 1.6.3.3.5 software (41, 42) were used to analyze the data. The games were watched from recordings obtained from TV Broadcast and directly recorded on the MacBook Air 13" computer, 2017. Data quality control is a basic requirement in observational methodology (43); therefore, data reliability and observer reliability were corroborated using Cohen's Kappa (44), via the "Compute simple statistic" and "compute Kappa" functions of the GDEQ-SDIS v. 5.1.23 (40), assessing intra- and inter-observer agreement (Table 2). Two observers carried out all the observations and data recording, having tested intra- and inter-observer reliability before the start of the process. Before starting the observations, the two observers underwent a period of training to achieve observers' reliability as recommended by Anguera et al. (45). After the training period, the observers carried out the observations and tested intra- and inter-observer reliability. Both observers obtained values above 0.79 in the Kappa test and held a session to discuss the recorded data and correct the recording criteria. An inter-observer Kappa test was also carried out and the value obtained (0.87) confirms inter-observer reliability. After they tested intra- and inter-observer reliability, they started to observe and register the games that were previously defined for each observer. Each observer was responsible for observing half of the games in the observational sample. During the process at the end of every four games (Euro 2020) and after every six games (Euro 2022, 2021, and 2023 WCh) observed, an intra- and

TABLE 1 Observational sample.

Competition	Euro 2020	WCh 2021	Euro 2022	WCh 2023
Games observed	34	34	28	36
No. of sequences 7 vs. 6 occurred	123	79	121	68

Euro, Men's European Championship; WCh, Men's World Championship.

TABLE 2 Kappa values obtained (minimum and maximum).

Value of Kappa	Euro 2020	WCh 2021	Euro 2022	WCh 2023
Intra-observer	0.79–0.91	0.84–0.96	0.87–0.96	0.92–0.97
Inter-observer	0.87–0.94	0.80–0.94	0.80–0.96	0.88–0.93

Euro, Men's European Championship; WCh, Men's World Championship.

inter-observer Kappa test was carried out. For the intra-observer test, the last game observed was used, and the observation was repeated 3 days later. For the inter-observer Kappa test, they previously defined which game would be observed by both observers to test inter-observer reliability. For intra-observer reliability, the minimum Kappa values were in the range of 0.79–0.91 and the maximum values were in the range of 0.91–0.97. For inter-observer reliability, the minimum values obtained between observers were in the range of 0.80–0.88, while the maximum values were in the range of 0.93–0.96. The above results for intra- and inter-observer reliability determine the quality of the data collected (46).

2.1.4 Questionnaire

The questionnaire was constructed and validated using the Delphi method, by debate and consensus between five experts in the field of Sports Sciences and Handball. After designing the instrument, it was applied to a group of adult participants. This version of the questionnaire was subject to a pilot study. In the pilot study, the questionnaire was handed to 14 handball coaches, at two different times, with an interval of 7 days. This pilot study aimed to test the instrument's reliability, internal consistency, and the protocol procedures that support its application. There were high levels of reliability (intraclass correlation coefficient 1.000–0.902; $p < 0.05$) and internal consistency ($\alpha = 0.787$, $p < 0.05$). The final version of the questionnaire, in Portuguese, English, French, and Spanish, consisted of 42 questions, with answers associated with a 5-point Likert scale (1 totally disagree to 5 totally agree), distributed across four sections: (i) personal data, training, experience, and current professional situation; (ii) perception and importance of 7 vs. 6 EG; (iii) the use of 7 vs. 6 EG in training and competition; and (iv) 7 vs. 6 EG in system offensive and defensive action.

2.1.5 Questionnaire sample

The questionnaire was completed by 156 coaches of both sexes (146 men and 10 women) from three continents (Africa, Europe, and South America) and 19 nationalities, with a mean age of 42.33 ± 11.87 years. Most of the coaches had at least a level 3 (61.4%), a mean of 12.77 ± 9.45 years of experience, and had coached teams at the national (45.5%) or international (33.3%) level.

2.1.6 Procedures

The questionnaires were made available via the Google Forms platform and were scattered through the National Coaches Association, Portuguese Handball Federation, Madeira Handball Association, European Handball Federation, and contacts with researchers from Spain, Iceland, and Uruguay who carried out its dissemination.

2.1.7 Statistics

A descriptive analysis (absolute and relative frequencies) of data from the games was performed via GSEQ software version 5.1.23. The lag sequential analysis was applied following the procedures by Bakeman and Quera (40, 47). Hoisan software version 1.6.3.3.6 was used to analyze the data using the polar coordinate technique (48). Descriptive statistics (mean and standard deviation) were used to characterize the sample collected through the questionnaire, in the variables under study. The dependence between nominal and ordinal variables was determined using the chi-square test, for example between the coaches' training and the perception and use of 7 vs. 6 EG. Spearman's correlations were used to determine the association between ordinal variables. The significance level adopted was 5%. The software used was SPSS version 27.0.

3 Results

3.1 Descriptive analysis from observational data

A descriptive analysis of the data (absolute and relative frequencies) was initially carried out, which allowed decisions to be made regarding subsequent analyses, both lag sequential analysis and polar coordinate analysis, as recommended by Anguera (49) and previously carried out and justified by Prudente et al. (7). A total of 4,236 events were recorded at the 391 offensive sequences registered using 7 vs. 6 EG strategy during the 132 games played by teams ranked 1–12 at four major tournaments between 2020 and 2023 (Euro 2020 and 2022, and WCh 2021 and 2023). The results show that the total number of goals scored in a 7 vs. 6 EG game situation were lower in the WCh compared to those in the Euro, following the trend of reducing the use of this strategy from one tournament to the other. An interesting fact is the verification of a tendency toward a decrease in effectiveness in the use of the 7 vs. 6 EG from the Euro 2020 (51.2%) to the WCh 2023 (48.5%). However, it can be highlighted that the teams classified in the first six places obtained values between 49% (2022) and 51.2% (2021), while there was a decrease in the effectiveness of the teams classified as 7th to 12th, with values that dropped from 50% to 41.7%, improving to 43.8% in the last competition (WCh 2023) (Table 3).

Table 4 shows that there was an evolution regarding the negative consequences of the use of this tactical option. Teams at Euro 2020 had relative success, considering that they conceded a goal after losing the ball in only 12.2% of cases; although the

TABLE 3 Goals scored playing 7 vs. 6 with empty goal and % of efficiency.

Competition	Euro 2020	WCh 2021	Euro 2022	WCh 2023
Total Goals scored in 7 vs. 6	63	39	56	33
% of goals by total sequences	51.2	49.4	46.3	48.5
% of goals/total sequences from teams classified from 1st to 6th place	51.6	49	53.1	50
% of goals/total sequences from teams classified from 7th to 12th place	50	50	41.7	43.8

Euro, Men's European Championship; WCh, Men's World Championship.
Comparison between teams classified between 1st and 6th place and teams classified between 7th and 12th place in each competition.

TABLE 4 Number of offensive sequences, in 7 vs. 6 situation, opponent responses and goals conceded.

Competition	Euro 2020	WCh 2021	Euro 2022	WCh 2023
Number of offensives sequences 7 vs. 6	123	79	121	68
Number of opponent responses	53	28	32	23
Goals conceded by teams attacking 7 vs. 6	15	12	17	10
% of goals conceded by total of responses from opponent	28.3	42.9	53.1	43.5
% of goals conceded by total of 7 vs. 6 attacks	12.2	15.2	14.1	14.7

Euro, Men's European Championship; WCh, Men's World Championship.

number of responses from the opponent was high, the effectiveness of that response was not high and resulted in a goal only 28.3% of the time. This relationship changed in the following competitions, with a decrease in the number of sequences (more pronounced in the WCh), in the number of responses from the opponent, and in the number of goals conceded by the teams that attacked 7 vs. 6 EG. Response effectiveness registered an increment that went from 28.3% in Euro 2020, to values of 42.9% and 43.5% and even higher than 50% in Euro 2022. This evolution denotes an improvement in teams handling the opponent responses to the use of the 7 vs. 6 EG strategy.

3.2 Descriptive analysis from questionnaire data

3.2.1 Perception and importance of 7 vs. 6 EG

Approximately three out of four coaches agree with the possibility of playing 7 vs. 6 EG (74.4% vs. 25.6%). There was no association between training, experience, and competition level and the coaches' opinion on the use of 7 vs. 6 EG ($p > 0.05$). Most coaches reported rarely or never using 7 vs. 6 EG, with coaches having less training (39%), less experience (42%), and coaching teams at lower (regional) levels (51.5%) reporting a higher proportion of never using this strategy ($0.458 < r < 0.231$, $p < 0.05$). It turns out that 40.3% of coaches do not support the application of the 7 vs. 6 EG rule and 35.3% are in favor of eliminating the rule. There were no significant differences in the proportion of coaches in favor and not in favor of the 7 vs. 6 EG rule according to training, experience, and level of competition ($p > 0.05$).

The lowest percentage in favor of eliminating the 7 vs. 6 EG rule was found among coaches with less experience (<5 years) (21.7%), while the percentage was higher among those with 5 to 10 years of experience (50%) and those with more than 10 years of experience (46.2%) ($\chi^2 = 10.998$, $p = 0.004$).

3.2.2 The use of 7 vs. 6 EG in training and competition

Coaches declared that the 7 vs. 6 EG rule brings little or no advantage (52.6%), regardless of training, experience, or level of competition ($p > 0.05$). Partial score (77.9%) and game time (69%) are mentioned as factors that influence the use of 7 vs. 6 EG. According to the coaches, being behind in the score (78.1%) and the last moments of the game are the best contexts in which to use 7 vs. 6 EG. The use of this strategy should also be conditioned by the tactical-technical quality of the players (94.3%), the team (89.1%), the experience of the players (84.6%), and the characteristics of the opponent (81.4%). The coaches' opinion is independent of their training, experience, and the level of competition in which they play ($p > 0.05$). Only one in ten coaches (9.7%) agree with the introduction of the 7 vs. 6 EG rule for players aged 15 year or less. There is a consensus among coaches on the age at which the 7 vs. 6 EG rule should be introduced (the majority argue that the rule should only be introduced from U16 (33.1%) and U18 (41.6%), regardless of training, experience, and level of competition ($p > 0.05$). One in three coaches (33.3%) stated that they never use the 7 vs. 6 EG rule in training, 38.7% use it once a week, 22.7% use it 2–3 times a week, and the remaining 5.3% use it at least four times a week. It was found that coaches with a higher level of training ($r = 0.193$, $p = 0.018$), more experience ($r = 0.54$, $p < 0.0001$), and who currently coach at a higher competitive level (international level) ($r = 0.330$, $p < 0.0001$) reported practicing the 7 vs. 6 EG rule more often.

3.2.3 7 vs. 6 EG strategy and opponent's defensive action

The majority of coaches (82.7%) surveyed indicated that the 7 vs. 6 EG rule affects the defensive system, with the 6:0 (42.9%) and 5:1 (36.5%) defensive systems causing the most difficulties in a 7 vs. 6 EG situation. Leading the attack to finish in a certain area is also mentioned as a defensive strategy in 7 vs. 6 EG (92.9%). A large majority of coaches (96.1%) agree that a fast throw-off mast be used as a strategy to fight the use of 7 vs. 6 EG by the opponent. The 7 vs. 6 EG rule affects space management in attacking play, according to most coaches (78.8%), forcing the opposing defense to retreat to 6 m, which is in line with the coaches' response regarding the defensive system, when they state that 6:0 is what creates the most difficulty over 7 vs. 6 EG. Therefore, the use of one or two pivots is an important strategy in the 7 vs. 6 EG attack and where the role of the central defender (in the case of the game with a pivot) and the pivots are recognized by the coaches. Among the specific positions, coaches highlight the importance of the pivot (31.4%) and the central playmaker (16%) in 7 vs. 6 EG with approximately one in three coaches (31.4%) highlighting the importance of all players. None of the questions were associated with the coaches' training, experience, or level of competition ($p > 0.05$).

3.3 Sequential analysis

A lag sequential analysis (40, 47) was performed to detect some patterns of association (explainable by more than chance) between a given behavior and other variables (50–53). To analyze the probability of association between the focal conduct "teams classified 1st–6th" and "teams classified 7th–12th" and the conditioned conduct "game time" when teams play 7 vs. 6 EG, some patterns were detected (Figure 1).

It should be noted that according to the results of the lag sequential analysis, the patterns of regular association, which occur beyond chance, are different in each competition. It should also be highlighted that the teams classified between 7th and 12th place have different patterns compared to the teams ranked among the first six in each competition: the probability of these teams using the 7 vs. 6 EG game in the last 5 min of the second half is significant (B4: 3.20) in Euro 2020, or during the first

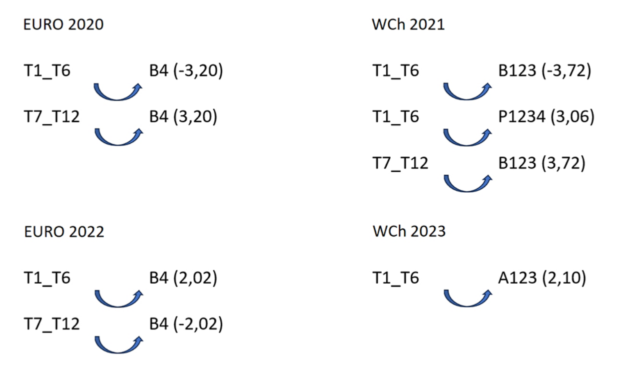

FIGURE 1
Association pattern between the focal conduct "teams," considering teams classified between 1st and 6th place and teams classified between 7th and 12th place, and the conditioned conduct "game time": A123, first half; B123, first 25 min of second half; B4, last 5 min of second half; P1234, extra time period; Euro, Men's European Championship; WCh, Men's World Championship.

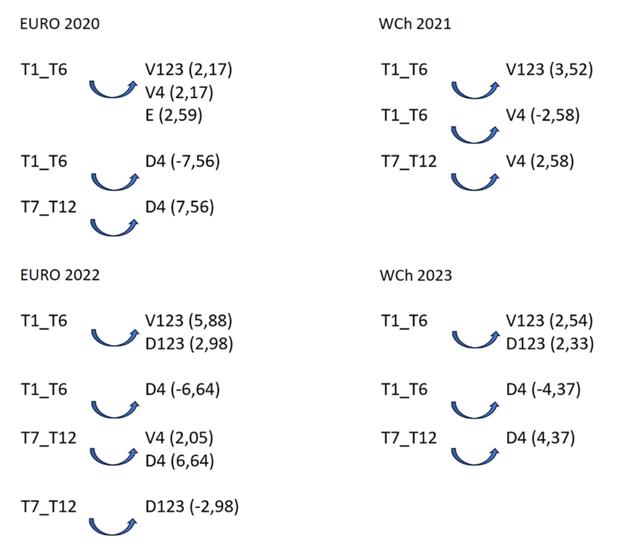

FIGURE 2
Association pattern between the focal conduct "teams," considering teams classified between 1st and 6th place and teams classified between 7th and 12th place, and the conditioned conduct "partial score": V123, winning by 1, 2, or 3 goals; D123, losing by 1, 2, or 3 goals; V4, winning by 4 or more goals; D4 – losing by 4 or more goals; E, draw; Euro, Men's European Championship; WCh, Men's World Championship.

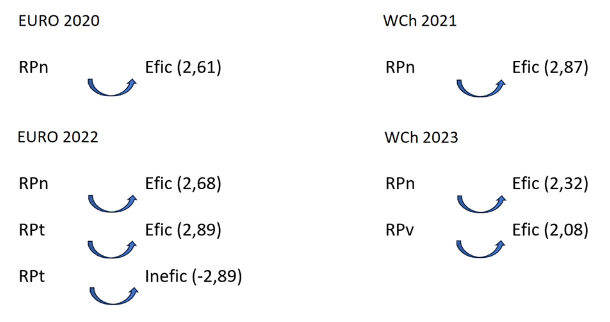

FIGURE 3
Association pattern between the focal conduct "finalization mode": breakthrough shot (RPn); wing shot (RPt); pivot shot (RPv), the conditioned conducts "efficiency," goal or 7 m (Efic), and no goal (Inefic). Euro, Men's European Championship; WCh, Men's World Championship.

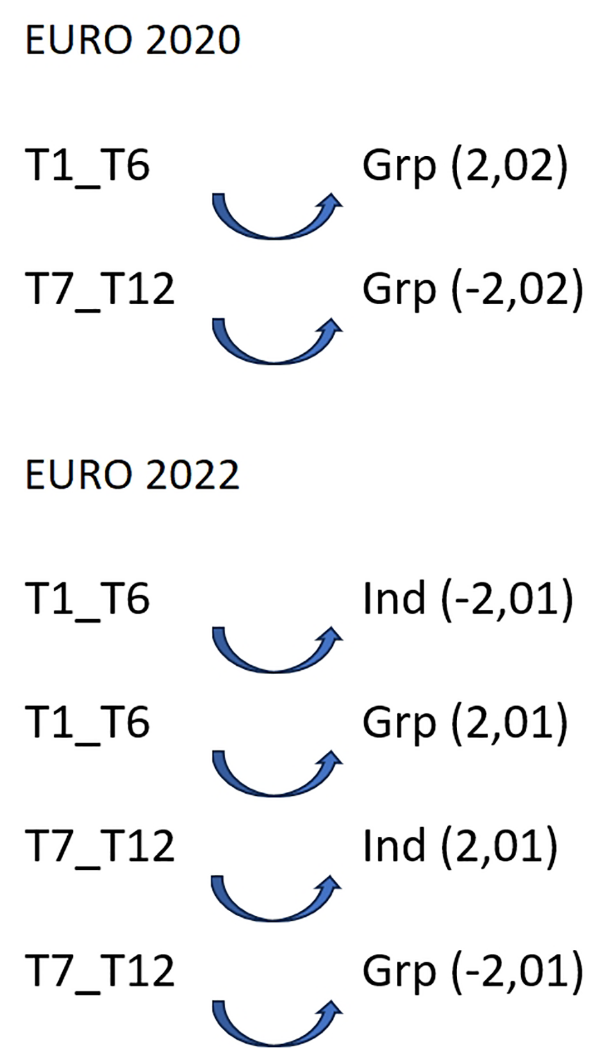

FIGURE 4
Association pattern between the focal conduct "teams classified 1st–6th" and "teams classified 7th–12th" and the conditioned conduct "tactical means" when teams play 7 vs. 6: Ind, individual tactical means; Grp, group tactical means; Euro, Men's European Championship.

25 min of the second half (B123: 3.72) in WCh 2021; however, in Euro 2022, there is a significant probability that teams ranked 7th–12th will inhibit the use of the 7 vs. 6 EG game in the last 5 min of the second half (B4: −2.02), with no pattern of use of 7 vs. 6 EG detected by these teams in WCh 2023. Regarding the teams classified in the top six places, five different patterns were detected: (1) significant probability of inhibition of the use of 7 vs. 6 EG in the last 5 min of the second half (B4: −3.20) in Euro 2020; (2) significant probability of inhibiting the use of 7 vs. 6 EG in the first 25 min of the second half (B123: −3.72); (3) significant probability of using the 7 vs. 6 EG game in extra time (P1234: 3.06) in WCh 2021; (4) significant probability of these teams using the 7 vs. 6 EG game in the last 5 min of the second half (B4: 2.02) in Euro 2022; and (5) using the 7 vs. 6 EG game in the first 25 min of the first half (A123: 2.02) in WCh 2023. To analyze the probability of association between the focal conduct "teams classified 1st–6th" and teams classified "7th–12th" and the conditioned conduct "partial score" (the result on the moment that begins the 7 vs. 6 EG rule), some patterns were detected (Figure 2).

In all competitions, some patterns were detected highlighting an association between "partial score" and final ranking. The results showed a difference between teams classified in the first six places and the teams classified as 7th–12th: teams classified in the 7th–12th positions decided to start using the 7 vs. 6 EG rule when they were losing by four or more goals (D4), as confirmed by adjusted residuals for each competition: Euro 2020 (7.56); Euro 2022 (6.64); and WCh 2023 (4.37). However, during WCh 2021, a different pattern was found: they used 7 vs. 6 EG when winning (V4) by four or more goals (2.58). For teams classified in the first six places, losing by four or more goals, was a pattern to inhibit the use of 7 vs. 6 EG (D4): Euro 2020 (−7.56); Euro 2022 (−6.64); and WCh 2023 (−4.37). At WCh 2021, it was found statistically significant that these teams, when they were winning by 1–3 goals (V123), used the tactical option

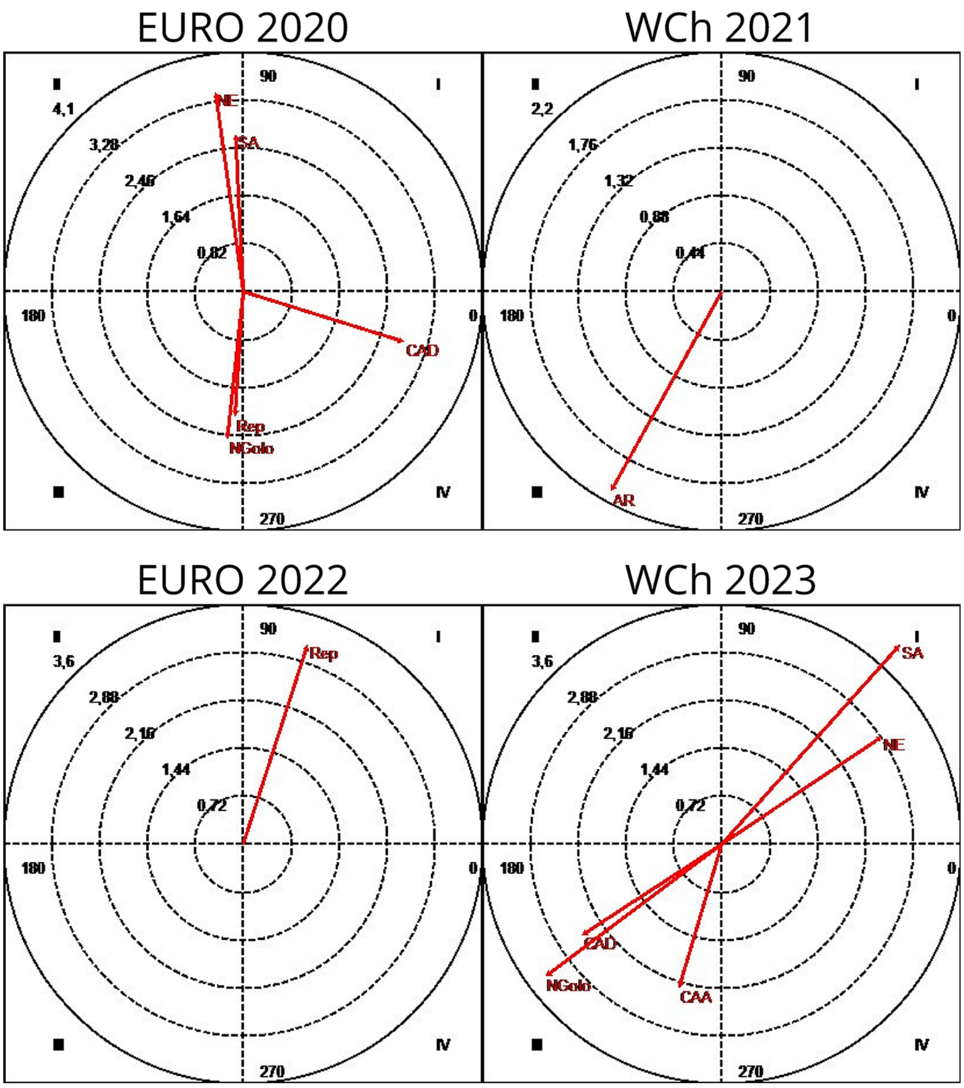

FIGURE 5
Polar coordinate analysis map: focal conduct "7 m goal" (7MG); conditioned conducts: fast attack (AR); throw-off (Rep); no attack (NE), teams abdicated of fast response; direct fast break (CAD); sustained fast break (CAA); no response (SA); goal, when the opponent response finished scoring a goal (Golo). Euro, Men's European Championship; WCh, Men's World Championship.

7 vs. 6 EG (3.52) as it was the case at WCh 2023, when they were losing by 1–3 goals (D123), a pattern of significant association was detected between teams and the D123 (2.98 and 2.33, respectively). Association patterns were found between the focal conduct "finalization mode" (RPn) (breakthrough shot) and the conditioned conducts "efficiency" (Efic) (goal or 7 meters) and "Inefic" (no goal) as shown in Figure 3.

To find a regular association pattern between focal conducts based on teams' ranking ("teams classified 1st–6th" and "teams classified 7th–12th") and the conditioned conducts based on "tactical means" ("Ind": individual tactical means and "Grp": group tactical means), a sequential analysis was performed when the teams played 7 vs. 6 EG (Figure 4).

As observed in Figure 4, in the two European tournaments, teams ranking 1st–6th activated the use of group tactical means (Grp) (Euro 2020 (2.02) and Euro 2022 (2.01)) as well as inhibited the use of individual tactical means in Euro 2022 (−2.01). For teams ranking 7th to 12th, the results showed quite the opposite: inhibiting the use of group tactical means in both Euro 2020 (−2.02) and Euro 2022 (−2.01), and with a significant probability that those teams used individual tactical means (2.01) when playing 7 vs. 6 EG. No patterns were found in WCh 2021 and 2023.

3.4 Polar coordinate analysis

A second analysis was performed by applying the polar coordinate technique. While a sequential analysis performs a prospective or retrospective analysis, a polar coordinate analysis performs a prospective and retrospective analysis and gives a vector map that shows how the different variables of the system interact (48). This technique allows us to determine the angles and quadrants in which the vector is located, as well as its length, establishing the type of relationship between the focal conduct

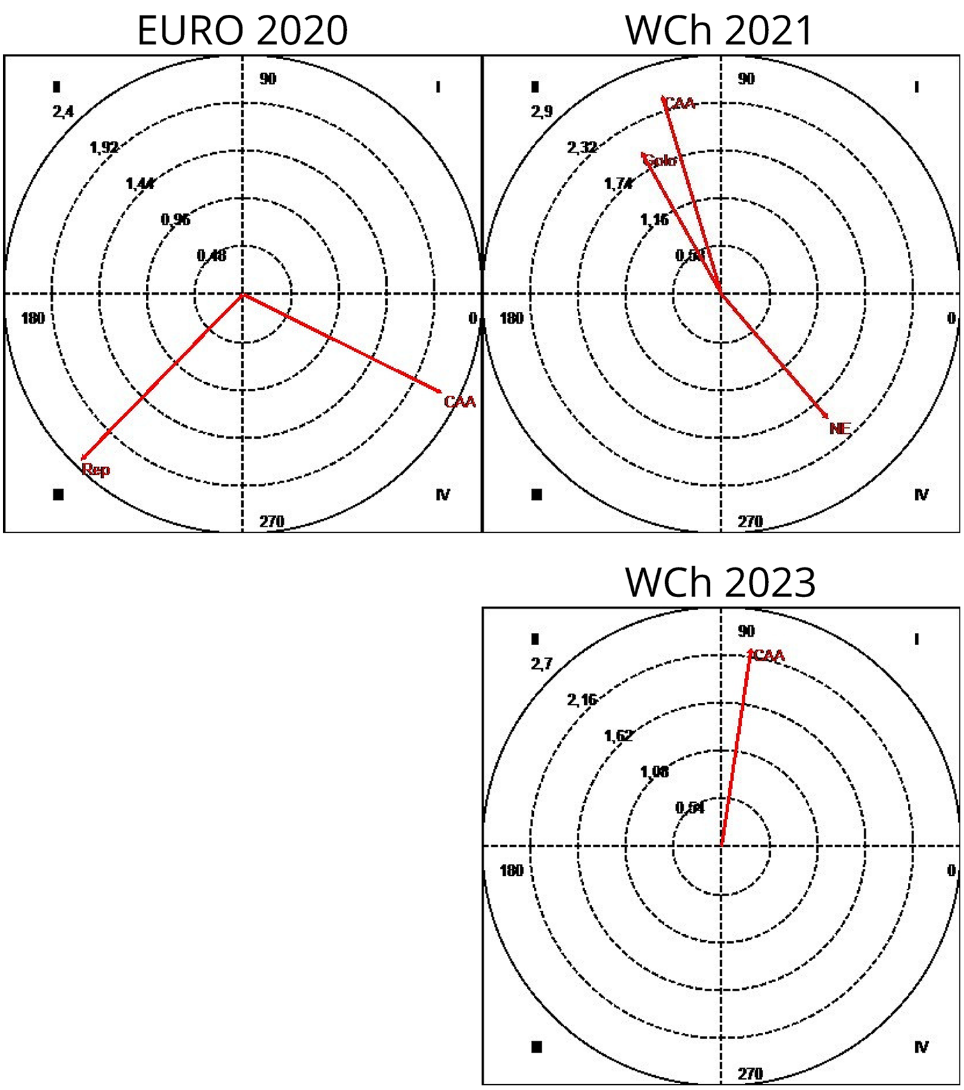

FIGURE 6
Polar coordinate analysis map: focal conduct "7 m no goal" (7MNG); conditioned conducts: throw-off (Rep); No attack, teams abdicated of fast response (NE); sustained fast break (CAA); goal, when the opponent response finished scoring a goal (Golo). Euro, Men's European Championship; WCh, Men's World Championship.

(given) and the conditioned conducts defined for each analysis. As mentioned by Prudente et al. (7), the length of the vector expresses the quantitative relationship between the focal conduct (given) and the conditioned conducts (the longer the vector, the stronger the intensity of the relationship between the conducts). The quadrant where the vector is placed expresses the qualitative relationship between these behaviors as follows (6, 54, 55):

Quadrant I (+ +): mutually excitatory given conduct and matching conduct.

Quadrant II (− +): inhibitory given conduct and excitatory matching conduct.

Quadrant III (− −): mutually inhibitory given conduct and matching conduct.

Quadrant IV (+ −): excitatory given conduct and inhibitory matching conduct.

Considering the focal conduct “7-m goal” (7MG) and conditioned conducts “throw-off” (Rep), “fast break” (CAD), “fast attack” (AR), “sustained fast break” (CAA), “no attack” (NE), and “no response”

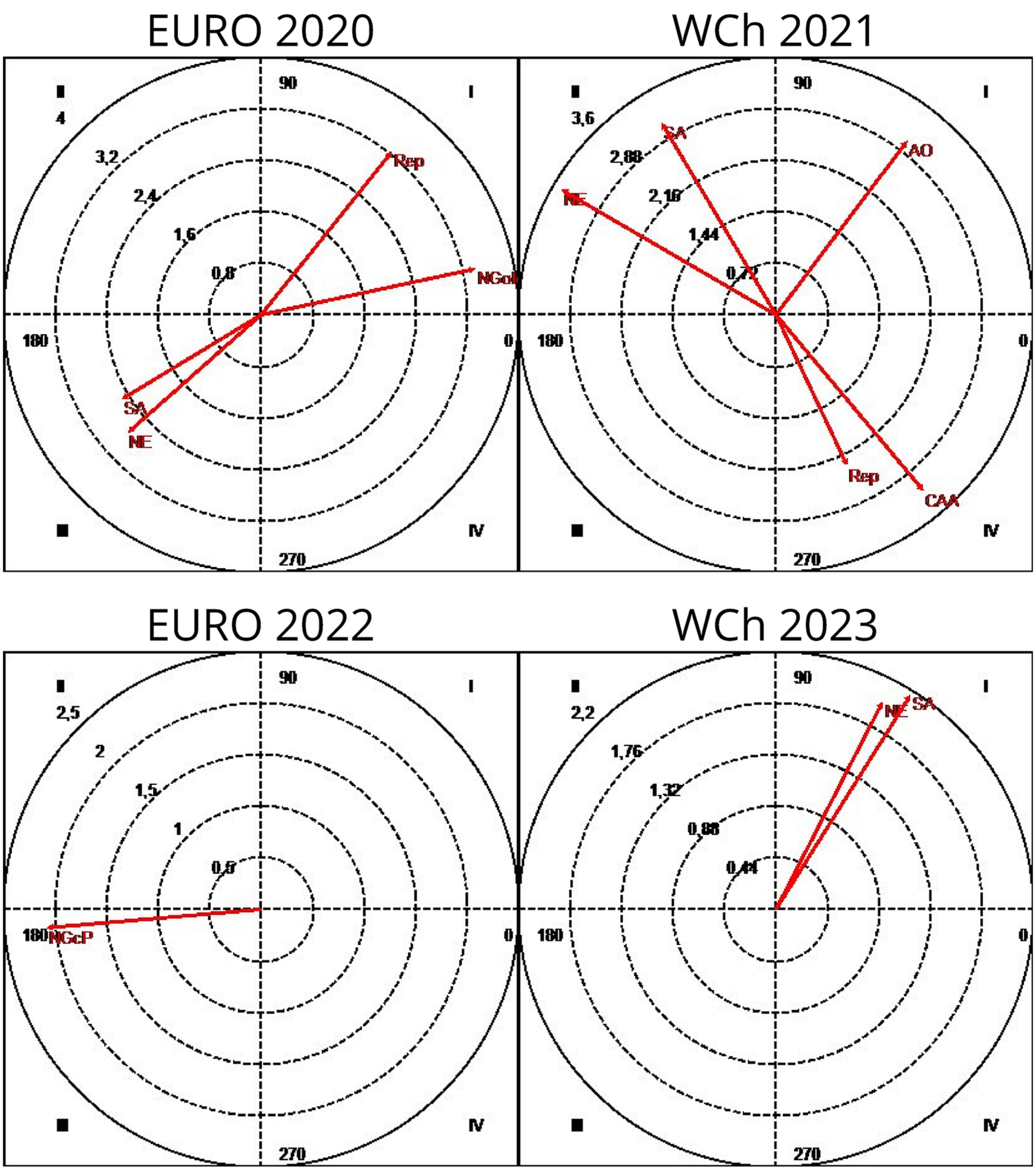

FIGURE 7
Polar coordinate analysis map: focal conduct “goal” (G); conditioned conducts: throw-off (Rep); no attack, teams abdicated of fast response (NE); sustained fast break (CAA); no goal, when the opponent response finished with a shot but no scoring a goal (NGolo); organized attack (AO); goal, when the opponent response finished with a shot scoring a goal (Golo); no response (SA). Euro, Men’s European Championship; WCh, Men’s World Championship.

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(SA), the conduct maps in Figure 5 were obtained. A first analysis of the vector maps shows the differences between the different competitions, including contradictory results. In none of the competitions analyzed did the 7MG conduct trigger the occurrence of an own goal. It is also worth noting that although this focal conduct activated fast REP in Euro 2022 and CAD in Euro 2020, the result of the goal response did not obtain significant results associated with 7MG, as a conduct inhibited or activated. However, it inhibited AR in WCh 2021, and in WCh 2023 it inhibited CAD and CAA, activating NE and SA as a response from the team that conceded the goal from 7 m.

Figure 6 shows the vector maps that explain the type of relationships found between the focal conduct "7 m no goal" (7MNG) and the conditioned conducts: "no attack" (NE)—teams abdicated of fast response; CAA—sustained fast break; and Golo when the opponent response finished scoring a goal. Some relationships were found between the focal conduct 7MNG and the conditioned conducts: NE, CAA, and Golo. At Euro 2020, the focal conduct 7MNG activated the CAA and there is the existence of a mutually inhibitory relationship with Rep. On the other hand, at WCh 2021, the focal conduct 7MNG inhibits

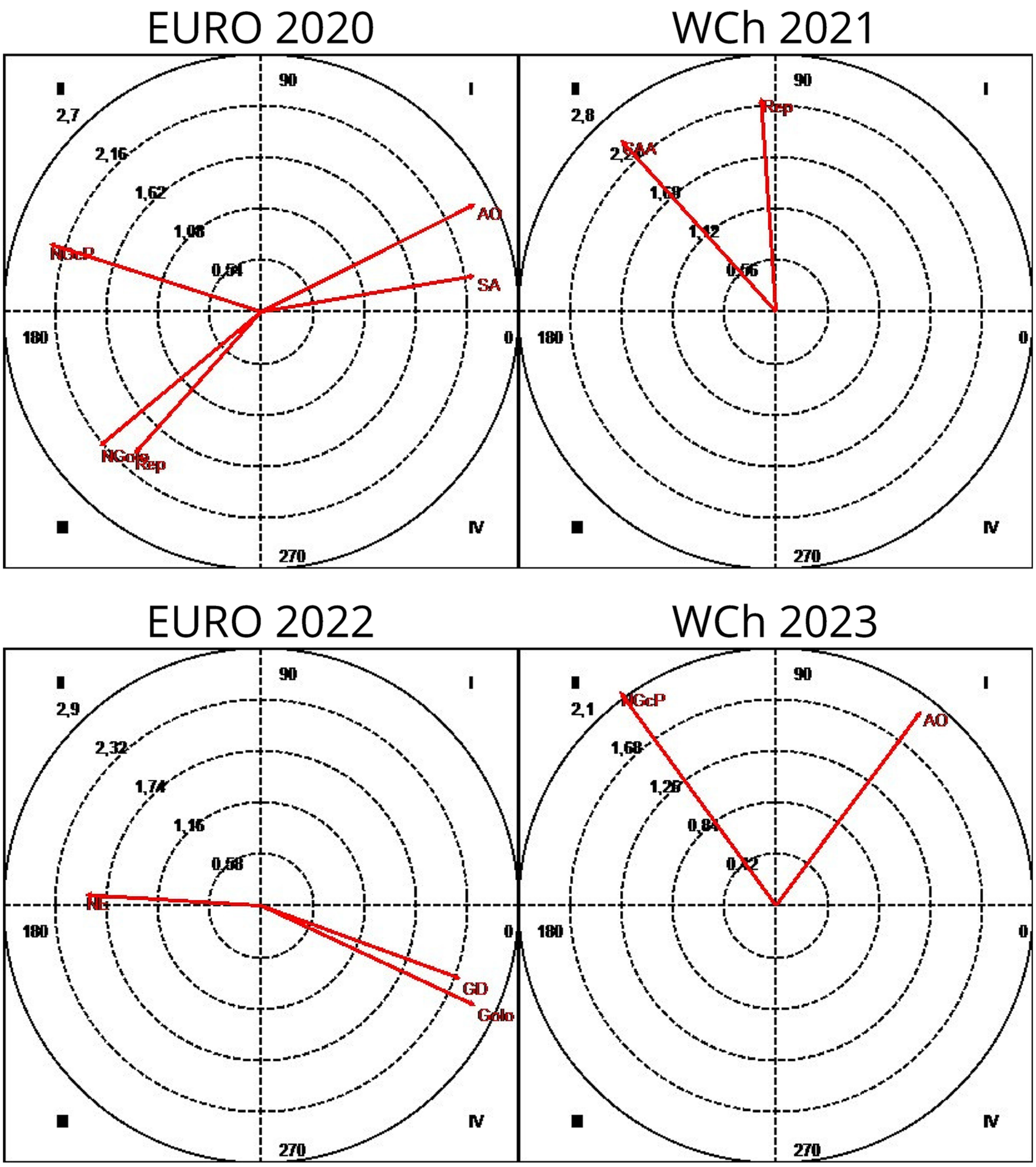

FIGURE 8
Polar coordinate analysis map: focal conduct "no goal" (NG); conditioned conducts: throw-off (Rep); no attack, teams abdicated of fast response (NE); sustained fast break (CAA); no goal, when the opponent response finished with a shot but no scoring a goal (NGolo); organized attack (AO); no response (SA); goal, when the opponent response finished scoring a goal (Golo); goal-to-goal attempt (GD); no goal with penalty (NGcP). Euro, Men's European Championship; WCh, Men's World Championship.

the occurrence of the CAA and is activated by it; and finally, at WCh 2023, the focal conduct 7MNG activates the CAA in a mutually excitatory relationship. At Euro 2022, no significant patterns of relationship between 7MNG and conditioned conducts were detected. However, at WCh 2021, a relation of inhibition of the Golo conduct, relative to the result of the opponent's response and activation of the focal conduct by it, was found as well as the existence of a relationship between the activation of the behavior NE and the inhibition of 7MNG.

As can be seen, based on the vector maps in Figure 7, obtained considering the focal conduct "G" (goal) and the "opponent's response" and its "opponent response result" as conditioned behaviors, a relationship of mutual activation was detected between G and Rep and Ngolo at Euro 2020, as well as a mutually inhibitory relationship between the same focal conduct and both NE and SA; on the map referring to WCh 2021, we observe the existence of a relationship of mutual activation between the focal conduct G and the AO and a relationship of rapid activation of Rep and CAA being inhibited by these. In Euro 2022, we only detected a significant relationship, of mutual inhibition, between the conduct NGcP and the focal conduct. Finally, at WCh 2023, we found two patterns of mutually excitatory relationship between the focal behavior G and the conditioned behaviors NE and SA.

Figure 8 presents the results having "no goal (NG)" as focal behavior and "opponent's type of response" as conditioned conducts. At Euro 2020, the focal behavior NG presents a mutually excitatory relationship with the conditioned behaviors AO and SA, inhibiting the occurrence of NGcP and being activated by it. NG it also presents a mutually inhibitory relationship with Ngolo as a result from opponent response and Rep behaviors. At WCh 2021, the following significant relationships were detected: NG inhibits and is activated by Rep and CAA. At Euro 2022, an activation relationship was detected between the NG focal conduct and the conditioned conducts GD and Golo when the opponent response finished scoring a goal, which in turn inhibited the NG focal conduct; NG inhibits NE and is activated by it. Finally, at WCh 2023, the focal conduct NG presents a mutually excitatory relationship with the AO conduct and inhibits NGcP being activated by it.

4 Discussion

The aim of this study was to contribute to deepening the knowledge of the use of 7 vs. 6 EG in handball, with an approach in which the observation of the teams' and players' behaviors during game actions was crossed with the coaches' perceptions and opinions about this strategy. Therefore, the study tries to understand the evolution of the 7 vs. 6 EG in the last 4 years of men's high-level international competitions (two Euro and two WCh) and verify how the perceptions and opinions of the coaches were whether confirmed or not by the results of the observation.

Based on the results obtained from the opinion of the coaches surveyed, the majority (74.4%) agree with this rule of playing with 7 vs. 6 EG, similar to the coaches' opinions reflected by Sousa et al. (23), which was 86.3%. Approximately one-quarter of those surveyed in the study (25.6%) was not in agreement, which was higher than the 13.7% found in the study by Sousa et al. (23), pointing out that the controversy generated by this rule has not yet been resolved. Although 64.5% of coaches stated that they did not agree with the elimination of this rule, in line with the 66% found in the study by Sousa et al. (22), 59% supported changes to it, which confirms that the debate continues among coaches. Complementing this opinion, most coaches (55.6%) questioned said they rarely or never used this tactical option, similar to the 56% found by Sousa et al. (23). According to Gilio et al. (29), the coaches highlighted two game situations where the option of attacking with an empty goal arises: when the team is outnumbered and thus seeks to balance and play 6 vs. 6 in attack; and in numerical equality when the aim is to improve the effectiveness of the attack by playing in superiority 7 vs. 6 EG. Moreover, Branco et al. (28) stated that coaches declared to use this strategy to slow down the pace of the game, reduce the physical contact of the players with the opponents, and in moments of the game when their team faces difficulties solving 6 vs. 6 situations in positional attack. Those statement refers to the occasional use of this possibility during the game, thus corroborating the results obtained in the present survey of coaches, where 62.8% of coaches claimed to use 7 vs. 6 EG rarely or sometimes. These statements are sustained by the observational data obtained at men's elite-level handball in the present study (from tournaments played between 2020 and 2023), which showed a decreasing tendency in the number of attacks carried out in 7 vs. 6 EG, going from an average per game of 3.61 7 vs. 6 EG attacks carried out in 2020 to 2.32 in 2021 and 1.89 in 2023 (despite an increase to 4.32 in 2022). The findings are similar to the registered decrease from 6.5% to 4.5% in the use of this strategy in the 2016–2017 and 2017–2018 German Men's First Handball League (19) as well as the decline observed at the Men's Euro and WCh between 2017 and 2020 (56).

The main reason for the low use registered may be related to training aspects, as 33.3% of coaches stated they never train the 7 vs. 6 EG game or only train once a week (38.7%) and only 22.7% train this game situation two or three times a week, which was also confirmed by players' statements (24) on training once a week (52.6%) or even zero times a week (20%). The trends toward a decrease in the percentage of goals scored in the total of 7 vs. 6 EG sequences carried out by teams in the present study (52.21% in Euro 2020, 49.36% in WCh 2021, 46.28% in Euro 2022, and a slight recovery to 48.53% in WCh 2023) could also be interpreted as a stabilization on the efficiency in attacking 7 vs. 6 EG. These results are also similar to the decrease in the novelty and efficacy in the use of the 7 vs. 6 EG strategy registered at men's Euro and WCh from 2017 to 2020 (56).

The results also show that the percentage of goals conceded, by the teams that attacked 7 vs. 6 EG in the opponent's total responses when they recovered the ball, went from 28.3% in Euro 2020 to 42.85% in WCh 2021 and 53.13% at Euro 2022, and then dropping to 43.48% in WCh 2023. The evolutionary trend in the percentage of goals scored when using 7 vs. 6 EG (in the range of 46.28%–52.21%), associated with an increasing trend in the percentage of goals conceded in relation to the responses of the teams that were defending against the 7 vs. 6 EG attack (range

28.3%–53.13%), leads to the interpretation that the teams went from a less structured and trained phase of using 7 vs. 6 EG to a phase of adaptation to this new rule. This was confirmed when 44.2% of the coaches surveyed agreed that teams using this tactical option must first carry out specific work. As can be seen from the results obtained from games data, teams were using this tactical option with more security. This indicates that tactical and strategic solutions were found in order to reduce the successful use of the 7 vs. 6 EG option. When teams attack 7 vs. 6 EG, it becomes necessary to successfully finish the attack scoring, so as not to allow the opponent to take advantage of the transition between the departure of the additional field player and the re-entry of the goalkeeper, as noted by Gilio et al. (29). This adaptation was also caused by an increase in the speed of play, because of the ball being placed quickly in the center of the court followed by a fast throw-off being performed. The fact is that reducing the time that the opposing goalkeeper has to return to the goal when replacing the additional field player will thus dissuade the opponent from using the option of playing 7 vs. 6 EG. Through this behavior of fast "throw-off," a quick response from the team defending 7 vs. 6 EG when conceding a goal can be performed. However, it should be noted that if we consider the percentage of goals conceded by the teams that opted for the 7 vs. 6 EG attack in relation to the total number of sequences in 7 vs. 6 EG, the variation was smaller: 12.20% at Euro 2020 and a maximum of 15.19% at WCh 2021, having stabilized in the last two competitions analyzed at 14.05% (Euro 2022) and 14.71% (WCh 2023).

The results obtained with the polar coordinated analysis, when considering the focal conduct "goal" (G) and conditional conducts the response of the other team, patterns of associations of mutual activation in the different championships were observed, but no significant results of activation relationship was found between the focal conduct "goal" (G) and the "goal" conduct (Golo) resulting from the defending team's response action. That means no significant negative consequences were found for teams that decide to use 7 vs. 6 EG option when they scored a goal. When performing the same analysis to identify some relation between the focal conduct "no goal" (NG) and the conducts related to the responses of the other team, a significant relation was found only at Euro 2022 when "no goal" (NG) activate "goal" (Golo) was found, but this one inhibits "no goal" (NG). All these results are in line with the findings cited by Gümüş and Gencoglu (17), highlighting that teams using 7 vs. 6 EG did not have greater efficiency in attack, nor did the use of this tactical option have negative consequences or increase the risk of conceding a goal for these teams. Moreover, the results are similar to those found by Trejo-Silva and Bonjour (56), which stated a better successful finalization efficacy when playing 6 vs. 6 with the goalkeeper at the goal (48.9%) against 7 vs. 6 EG (41.9%).

The coaches surveyed have the perception that 7 vs. 6 EG brings little or some advantage (52.6%). However, they indicate that "partial score" (77.9%) and "game time" (69%) influence whether 7 vs. 6 EG is used. Coaches refer to being behind in the score (65.8.1%) and the final moments of the game as privileged situations in which to use 7 vs. 6 EG, while 9.6% of coaches refer to using it when they are tied and only 5.3% when they are winning. Prudente et al. (27) obtained similar results, since most of coaches (65.8%) consider that game time influences the use of the 7 vs. 6 strategy with an "empty goal," 92.2% consider that this use occurs in the final moments of the game, and 74.7% of respondents stated that "partial score" influences the use of 7 vs. 6 EG, with 90.7% considering that the team being at a disadvantage also influences its use. Haugen and Guvåg (15) mentioned that an additional field player will allow numerical superiority in attack, both for the best and the worst teams; however, according to these authors, the risk of playing with an empty goal can allow a more skilled opponent to win the ball, both for goalkeeper saves as per a better defensive behavior and scoring easily in an empty goal.

The results of the lag sequential analysis carried out to analyze the probability of association between the focal conducts "teams classified 1st–6th" and "teams classified 7th–12th" and the conditional conduct "game time" when teams play 7 vs. 6 EG has detected some patterns that confirm the opinions and perceptions of the coaches: "game time" activates the use of 7 vs. 6 EG by teams. Regular association patterns of using 7 vs. 6 EG. were detected during the following periods of game time: between 30′ 01″ and 55′ of the second half ("B123", 3.72); the period of the game between 55′ 01″ and 60′ of the second half ("B4", 2.02), the extra time period of the game ("P1234", 3.06); and, only at WCh 2023, between 0′ and 25′ of the first half ("A123", 2.10). Therefore, it can be confirmed that the probability of the game periods in the second half and extra time ("B123," "B4," and "P1234") being associated with the use of 7 vs. 6 EG is significant. This confirms the results of Gilio et al. (29), who stated that the use of the empty goal was related to the characteristics of the available players and the context of the game, particularly the game score and time. In addition, the results by Neuberg and Thiem (19) showed that the efficiency of using an additional field player depends, in a way, on timing, as was also declared by coaches when interviewed by Branco et al. (28) and Krahenbühl et al. (25, 26). The coaches' perception that "partial score," namely, when losing, is a prime situation in which to start using 7 vs. 6 EG, as expressed by 78.1% of questioned coaches, is confirmed by the results from the sequential analysis that show the teams classified 7th–12th when losing by four goals (D4) presented a significant probability to use this strategy at Euro 2020, Euro 2022, and WCh 2023. For teams classified between 1st and 6th places, a pattern of regular association with partial score when losing by one, two, or three goals (D123) was found at Euro 2022 and at WCh 2023. These results are in line with those in the study by Prudente et al. (7), where the teams show they preferred using 7 vs. 6 EG when the result was a momentary defeat by one, two, or three goals (D123) and they were behind by four or more goals (D4).

According to Gilio et al. (29), in the study carried out on the opinion of Brazilian coaches regarding the use of the additional field player, all coaches highlighted that the result associated with playing time influences whether the additional field player will be used. The authors also stated that game time proved to be relevant in the decision to opt for the 7 vs. 6 EG attack, especially when the teams were losing in the final minutes of each half of the game. Moreover, coaches also stated that playing 7 vs. 6 EG prevents defensive pressure, and a slightly more open defense, forcing the opponent to play more with blocking and less with interception, pressure, and direct contact, suggesting that short movements to attack empty spaces were recommended, to the detriment of one-on-one actions. Moreover, coach participants in the study by Branco et al. (28) also stated the same idea when analyzing the context of using 7 vs. 6 EG in terms of controlling the physical impact during a match or even during a period of a tournament. The results of the lag sequential analysis performed in this study apparently confirm this assumption: the results obtained show the existence of regular patterns of association.

Regarding the type of shot, the results show that the "penetration shot" (RPn) is associated with the effectiveness of the attack in all observed competitions and the "pivot shot" (RPv) at the WCh 2021.

When analyzing the use of the tactical means by teams, although we only achieved significant results at Euro 2020 and Euro 2022, we found differences between teams classified from 1st to 6th to the teams classified between 7th and 12th place, where the better classified teams activate group tactical means and the other teams activate the individual tactical means. In the analysis performed with the lag sequential analysis and the polar coordinate analysis, we did not find any pattern where the 9 m shot was a part of a pattern detected. Prudente et al. (7) also analyses the type of shot and observed that the 6 m shot was most common in all teams observed when they play 7 vs. 6 EG, considering it is a consequence of most teams choosing to play with two wing players and two pivots.

5 Conclusion

The results obtained and analyzed allow us to state that coaches, despite agreeing that the 7 vs. 6 EG rule corresponds to an evolution of the game, defend changes to it. Considering the results of the survey and the analysis of the observational records, it can be seen that the use of the rule by teams has evolved, with more punctual use and ensuring countermeasures to avoid conceding a goal in the opponent's response. Teams use this strategy mainly when they are at a disadvantage on the scoreboard, highlighting a difference between the teams ranked 1st–6th and the teams ranked 7th–12th: the former use the 7 vs. 6 EG game in a more varied way in "game time" and "partial score," while the latter opt for the 7 vs. 6 EG rule when they are behind by four goals or more and especially at the end of the game. The results indicate that training in this specific game situation still does not occur frequently to improve the efficiency of the 7 vs. 6 EG attacks. Clearly, this is an important indication for coaches.

6 Future research

Future research should also consider field players and goalkeepers, in addition to coaches, as well as data obtained through the systematic observation of player and team behavior. It will also be important to consider the 6 vs. 6 EG game in addition to 7 vs. 6, and use the T-pattern in data analysis, to discover and analyze hidden repeated temporal and often multimodal patterns in behavior, as mentioned by Pic et al. (38).

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval were not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the patients/participants or patients'/participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

JP: Conceptualization, Formal Analysis, Methodology, Supervision, Validation, Writing – original draft. AC: Conceptualization, Formal Analysis, Investigation, Methodology, Software, Writing – original draft. AR: Formal Analysis, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing. JM: Formal Analysis, Investigation, Software, Writing – review & editing. CF: Conceptualization, Investigation, Writing – review & editing. HL: Conceptualization, Investigation, Writing – original draft. AT-S: Formal Analysis, Investigation, Methodology, Validation, Writing – review & editing. DS: Conceptualization, Formal Analysis, Investigation, Methodology, Software, Validation, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fspor.2024.1354623/full#supplementary-material

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Effects of Baduanjin practice on emotional, attention and cognitive function in acupuncturists: protocol for a clinical randomized controlled neuroimaging trial

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Background: In Chinese medicine, the mental focus and emotional stability of acupuncturists are key to optimal clinical outcomes. Many renowned acupuncturists utilize Traditional Chinese Qigong practices to enhance their concentration and emotional regulation abilities. Nevertheless, the existing literature lacks comprehensive evidence addressing this matter.

Methods: This study will enroll 99 acupuncturists and randomly allocate them to one of three groups: Baduanjin, aerobic exercise, or a waiting-list control. The Baduanjin group will undertake 24 weeks of training, with three one-hour sessions weekly. The aerobic group will engage in brisk walking for the same duration and frequency. The control group will not receive any specific training. Assessments of emotion regulation, attention, cognitive functions, finger sensation, and athletic ability will be conducted at baseline (−1 week), mid-intervention (12 weeks), and post-intervention (24 weeks). Additionally, 20 participants from each group will undergo fMRI scans before and after the intervention to explore brain functional and structural changes relating to emotion, attention, cognition, motor skills, and sensory perception.

Discussion: This study aims to contribute valuable insights into the effectiveness of Qigong practice, specifically Baduanjin, in enhancing emotional regulation, attention, and cognitive functions in acupuncturists and to investigate the neuroimaging mechanisms behind these effects.

Ethics and dissemination: Approved by the Sichuan Regional Ethics Review Committee on Traditional Chinese Medicine (No. 2023KL – 118) and adhering to the Declaration of Helsinki. Results will be shared through policy briefs, workshops, peer-reviewed journals, and conferences.

Clinical trial registration: www.chictr.org.cn, ChiCTR2300076447.

KEYWORDS

acupuncturist, Baduanjin practice, fMRI, neuroimaging, emotion regulation, cognition, attention

Background

Acupuncture, now prevalent in 196 countries and regions worldwide, has undergone rapid development and is increasing global acceptance (Liu, 2023). This traditional intervention, deeply rooted in diagnostic assessments, acupoint selection, and adherence to medical guidelines, requires acupuncturists to maintain unwavering focus and emotional calm. Such qualities are crucial for effective treatment, as highlighted in the foundational text of Traditional Chinese Medicine, Huangdi Neijing (Fu and Yang, 2019).

Qigong, a longstanding practice among Chinese acupuncturists, emphasizes the regulation of the body, breath, and mind. Within the diverse array of Qigong forms, Baduanjin emerges as a particularly popular method. Distinguished by its combination of deliberate movements, focused attention, deep breathing, and relaxation, Baduanjin is recognized as a safe and effective form of aerobic exercise. It adheres to the established laws and theories of Qigong in traditional Chinese medicine (Koh, 1982; Fang et al., 2021), with a distinctive focus on harmonizing the mind and body (An et al., 2008).

Recent scientific studies have illuminated the extensive health benefits of Baduanjin across various demographic groups and health conditions. Clinical research has revealed Baduanjin's potential to bolster physical health, enhance life quality, and improve emotional well-being in healthy individuals (Cheng, 2015; Liao et al., 2015; Zou et al., 2018a). Systematic reviews have demonstrated its effectiveness in reducing symptoms of depression and anxiety in those with physical or mental health challenges (Zou et al., 2018b). Moreover, Baduanjin has shown efficacy in enhancing cognitive functions, including memory and executive function, particularly in older adults with mild cognitive impairment (Tao et al., 2019). Additionally, it has been linked to positive outcomes in various conditions, such as Parkinson's disease (Liu et al., 2019; Xia et al., 2019), hypertension (Xiong et al., 2015), chronic obstructive pulmonary disease (Liu et al., 2018), type 2 diabetes (Wen et al., 2017), low back pain, and knee osteoarthritis (An et al., 2013; Li et al., 2019).

While many skilled acupuncturists incorporate Traditional Chinese Qigong practices to refine their concentration and emotional regulation, thus improving their acupuncture techniques and effectiveness (Zou et al., 2021), rigorous, evidence-based medicine trials are lacking to substantiate the efficacy of these practices. Moreover, the underlying mechanisms driving these benefits remain largely unexplored.

Neuroimaging technologies, including functional magnetic resonance imaging (fMRI), positron emission tomography (PET), electroencephalography (EEG), and functional near-infrared spectroscopy (fNIRS), have revolutionized the study of neural activity. Among these, fMRI stands out for its convenience, non-invasive nature, and comprehensive brain coverage. This has led to its widespread application in neurology, psychiatry, and cognitive psychology research (Rashid and Calhoun, 2020). Prior neuroimaging studies have identified distinct differences in sensory-motor specialization (Dong et al., 2014, 2015) and emotional control (Dong et al., 2013) between acupuncturists and non-acupuncturists, likely attributable to the unique skills acupuncturists develop in clinical settings.

Given this background, we hypothesize that Baduanjin practice may significantly enhance emotion regulation, cognitive functioning, finger sensation, and motor skills. The aim of this clinical neuroimaging study is to assess the impact of long-term Baduanjin practice, regular aerobic exercise, and a waiting-list control group on these functions. Furthermore, the study intends to explore the neural mechanisms underpinning these effects.

Objective

(1) To evaluate the effects of Baduanjin exercises on emotion control, attention, and cognitive abilities compared to regular aerobic exercise and a control group on a waiting list.

(2) To visually demonstrate the impact of Baduanjin exercises on brain function related to emotion regulation and its influence on associated networks, including attention, cognitive abilities, motor skills, and sensory functions.

Hypotheses

Acupuncturist Long-term participation in Qigong will differ significantly from aerobic and waiting exercises in terms of emotional cognition and attention.

> *H1*: Long-term participation in Qigong, specifically Baduanjin, is expected to markedly improve acupuncturists' capabilities in emotion regulation, attention, and cognition.
>
> *H2*: It is also anticipated to cause observable changes in the structure and functional dynamics of specific brain regions.

Methods and analysis

Study design

This single-center, parallel randomized controlled clinical trial will enroll 99 eligible subjects from Chengdu University of Traditional Chinese Medicine.

Participants

The trial aims to recruit 99 participants from the School of Acupuncture and Tuina at Chengdu University of Traditional Chinese Medicine. Recruitment will be facilitated through various channels, including campus radio broadcasts, on-campus advertising, and online platforms.

They will be randomly assigned in a 1:1:1 ratio to the Baduanjin group, the aerobic exercise group, or the waiting-list group.

Procedure

The study's physical and psychological outcomes will be evaluated at three key intervals: one week before the intervention, at 12 weeks (mid-intervention), and at 24 weeks (post-intervention). Additionally, 20 individuals from each group will be selected randomly for pre-and post-intervention fMRI scanning. The study's process and timeline are depicted in Figure 1 and Table 1.

Inclusion criteria

Subjects will be recruited if they:

① Be aged between 18 and 25 years;
② Be right-handed;
③ Provide informed consent;
④ Be a full-time acupuncture student with completed courses in acupuncture and moxibustion (45 h), meridians and acupoints (84 h), and possess clinical practice experience, as evidenced by passing semester examinations.

Exclusion criteria

Subjects will be exclusion if they:

① Have chronic pain conditions, a history of head trauma with loss of consciousness, or intellectual disabilities;
② Are unable to comply with project requirements;
③ Suffer from psychiatric, respiratory, cardiovascular, or renal illnesses;
④ Are pregnant, planning a pregnancy, or lactating;
⑤ Have a history of alcohol or substance abuse/dependence;
⑥ Show evident organic lesions or severe cranial anatomical asymmetry;
⑦ Have contraindications for MRI, such as claustrophobia or non-removable metal in the body;

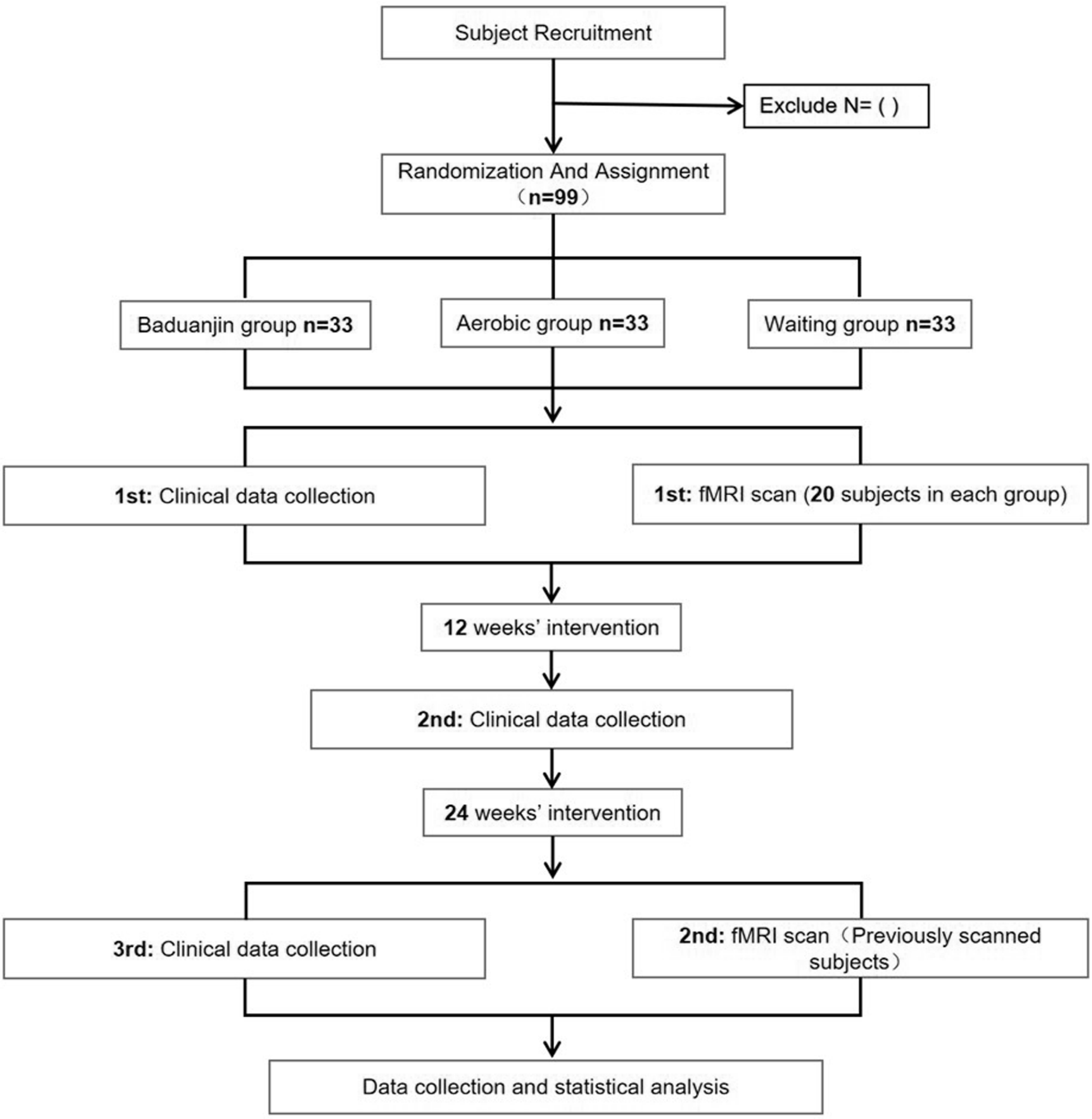


FIGURE 1
The roadmap of the study process.

TABLE 1 Schedule of the trial.

Items			Study process			
			Baseline period	Intervention period (0-24 week)		
Time point			1-week	0-week	12-week	24-week
Screening and preparation						
Informed consent			√			
Randomization and allocation			√			
Coaching seminar			√			
Intervention						
Baduanjin group				√	√	√
Aerobic exercise group				√	√	√
Waiting group				√	√	√
Clinical outcomes measurement	*Primary outcomes*	*Emotional control*				
		SPQ	√		√	√
		IRI	√		√	√
		POMS	√		√	√
		CD-RISC-25	√		√	√
		ECS	√		√	√
		Attention control				
		Schulte table software	√		√	√
		Cognitive function				
		CFS	√		√	√
	Secondary outcomes	*Hand motor function*				
		Hand grip strength	√		√	√
		Finger pinch strength	√		√	√
		Purdue pegboard	√		√	√
		Hand sensory				
		Touch-Test	√		√	√
		Two-Point test	√		√	√
		Acupuncture test	√		√	√
Image scanning						
fMRI			√			√
Subject safety						
Laboratory examination			√			
AEs				√	√	√

This study includes a 1-week advance baseline period and a 24-week intervention period for each participant.
SPQ, the Situational Pain Questionnaire; IRI, the Interpersonal Reactivity Index; POMS, the profile of Mood States; CD-RISC-25, the Chinese version of the Connor-Davidson Mental Toughness Scale; ECS, the Emotional Contagion Scale; CFS, the Cognitive Flexibility Scale; AEs, Adverse events. Laboratory test: including routine examination of blood, urine, and stool, blood biochemical test (including liver and kidney function), and electrocardiogram examination.

⑧ Engage in long-term regular practice of Qigong, martial arts, dance, aerobics, sparring, or taekwondo.

Sample size estimation

This preliminary exploratory clinical randomized controlled neuroimaging trial is informed by similar studies and the minimal sample size guidelines for clinical investigations (Yuen et al., 2021). Accounting for a potential 10% dropout rate, we aim to enroll 33 subjects per group, totaling 99 subjects across three groups. A previous neuroimaging study (Szucs and Ioannidis, 2020) indicates that an imaging sample size of more than 15 per group yields reliable and consistent results. Therefore, 20 subjects from each group will be randomly selected for functional magnetic resonance imaging (fMRI) scans.

Subjects safety

Prior to the trial, a detailed evaluation of the subjects' medical histories will be conducted. Routine examinations, including blood, urine, and fecal tests, will be performed before and after the intervention. Electrocardiography tests will also be administered pre-intervention. All adverse events following the intervention will be descriptively documented in the Case Report Form (CRF). Severe adverse events will be closely monitored, managed, and followed up, with immediate reporting to the Ethics Committee within 24 h of occurrence (Harriss et al., 2019).

Randomization and blinding

Given the nature of this trial, blinding of subjects and exercise coaches is not feasible. The random allocation sequence will be generated using SPSS 26.0 software (SPSS Inc., Chicago, IL, United States) to assign treatments. Allocation will be concealed in sealed, opaque envelopes, opened by the subject management center in sequential order according to subject serial numbers. Subjects will then be allocated to the respective trial groups and adhere to the exercise intervention protocol. A dedicated project manager, separate from the exercise coaches, will oversee the random allocation sequence and the blinding process. The project manager and exercise coaches will not participate in outcome assessments, and likewise, outcome assessors and the statistician will not be involved in subject screening or allocation. The study ensures a strict delineation of roles among researchers, operators, and statisticians.

Intervention

Intervention regimen

Previous research (Health Qigong Management Center of General Administration of Sport of China, 2003) indicates that participants in both the Baduanjin and aerobic exercise groups engaged in 60-min sessions, three times weekly, for a duration of 24 weeks. Subjects' energy expenditure and heart rate (HR) during training will be monitored using a Polar HR monitor (Mio Sports SD).

Baduanjin group

In accordance with the Health Qigong Management Center of General Administration of Sport of China (2003), the Baduanjin group will undergo 24 weeks of training. Each session will last 60 min, comprising a 10-min warm-up, 40 min of Baduanjin exercises, and a 10-min cool-down. This regimen encompasses 10 postures, including preparatory and finishing positions (Figure 2). Supervision and instruction will be provided by a senior social sports instructor with over 5 years of teaching experience. The week preceding the training will feature professional theoretical and movement instruction.

Aerobic exercise group

Participants in the aerobic exercise group will engage in brisk walking sessions, each lasting 60 min. This includes a 10-min warm-up, 40 min of brisk walking, and a 10-min rest period. Training duration and frequency will mirror those of the Baduanjin group. Professional coaches will guide these sessions, ensuring that exercise intensity remains within 55–75% of the participants' reserve heart rate, consistent with Baduanjin group guidelines.

Waiting-list group

The waiting-list group will not participate in any specific exercise regimen. Instead, they will be instructed to maintain their regular activity habits and provide monthly exercise reports.

Outcome measurements

Outcome measurements will be conducted by trained independent assessors, and all results will be recorded, irrespective of subject completion status. The study timeline, including enrollment, interventions, assessments, and visits, is outlined in Table 1.

Primary outcome measurement

Primary outcomes focus on attention control, cognitive function, and emotional control, assessed using various tools:

A Schulte Table Software (Prokopenko et al., 2013) for evaluating concentration and attention switching.
B Cognitive Flexibility Scale (CFS) (López et al., 2022) for assessing cognitive flexibility.
C To evaluate the capacity for regulating emotions: Emotional Contagion Scale (ECS) (Doherty, 1997) for measuring susceptibility to others' emotions.

Secondary outcome measurement

Secondary outcomes involve additional emotion regulation measures and hand function assessments:

Situational Pain Questionnaire (SPQ) (Stangier et al., 2021): A self-report tool with robust psychometric properties. Interpersonal Reactivity Index (IRI) (Escrivá, 2004): Commonly used for empathy assessment. Profile of Mood States (POMS) (Shahid et al., 2011): Evaluates affective changes during the assessment period. Chinese version of the Connor-Davidson Mental Toughness Scale (CD-RISC-25) (Connor and Davidson, 2003): A brief self-rated tool for quantifying resilience.

Hand motor function is assessed using the Jamar Hand Grip Strength Meter (Wiegert et al., 2022), Jamar Finger Pinch Strength Meter (King, 2013), and Purdue Pegboard Test for manipulative dexterity (Tiffin and Asher, 1948). Hand sensory function is evaluated using the Touch-Test Mono-filament Test (Kaluga et al., 2014), Two-Point Discrimination Sensory Test (Dellon et al., 1987), and a Composite Acupuncture Test developed by the researchers (see Table 2 for details).

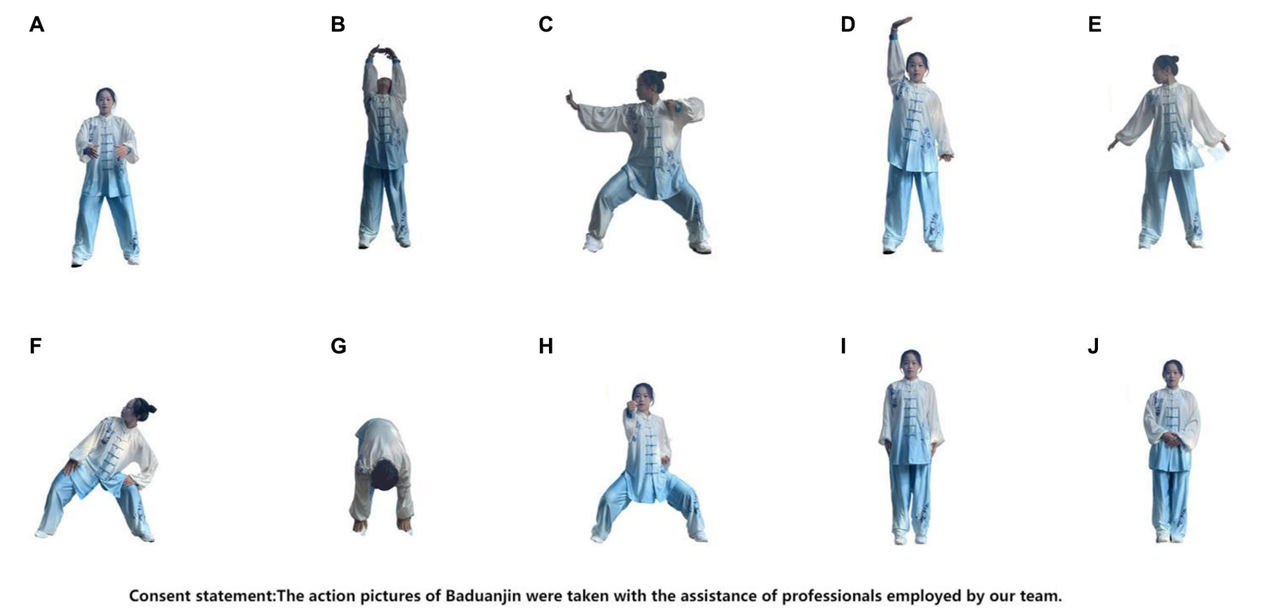
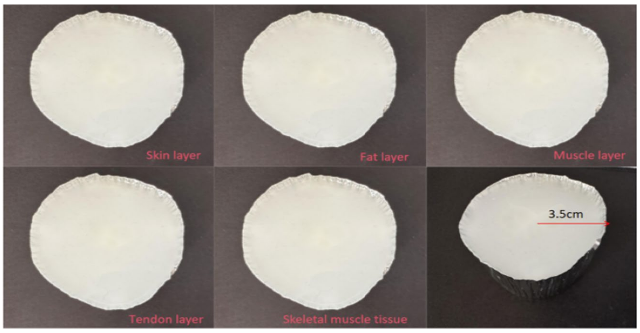
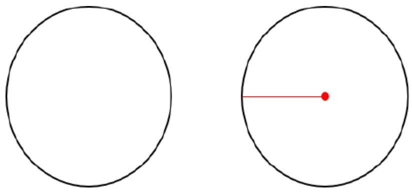


FIGURE 2
The action pictures of Baduanjin were taken with the assistance of professionals employed by our research team. **(A)** Preparation posture. **(B)** Prop up the sky with hands to regulate the triple energizer. **(C)** Draw a bow on both sides like shooting a vulture. **(D)** Raise a single arm to regulate the spleen (Pi) and stomach (Wei). **(E)** Look back to treat five strains and seven impairments. **(F)** Sway head and buttocks to expel heart (Xin)-fire. **(G)** Pull toes with both hands to reinforce the kidney (Shen) and waist. **(H)** Clench fists and look with eyes wide open to enhance strength and stamina. **(F)** Rise and fall on tiptoes to dispel all diseases. **(J)** Ending posture.

TABLE 2 **Instructions for the acupuncture test.**

Molds: five human silicone molds that tested by a professional senior acupuncture physician, the hardness of the mold was simulated for the corresponding human skin, fat, muscle, tendon, and skeletal muscle tissue, respectively.
Test items: Sensory test, subjects will acupuncture the center of the mold circle and rank the mold hardness within 15 s in blinding. Accuracy test, the right circular sticker was applied to the mold's surface, and subjects were instructed to puncture the sticker's center. The measurement was taken of the separation between the sticker's pinhole and the circle's center. Depth test, the subjects needled the mold with the same hardness such as muscle layer, and the distance of the needle body was measured.

fMRI outcome measurement

MRI data will be acquired using a 3.0-T GE MR750 scanner (GE 3.0 T MR750, Wauwatosa, WI, United States) with an eight-channel phase-array head coil at the University of Electronic Science and Technology of China's MRI Center.

Scanning parameters include: Structural imaging: Repetition time (TR)/Echo time (TE) = 1900 ms/2.26 ms; slice thickness = 1 mm; 30 slices; matrix size = 128 × 128; field of view (FOV) = 256 × 256 mm. BOLD-fMRI: TR/TE = 2000 ms/30 ms; flip angle = 90°; 30 slices; matrix size = 128 × 128; FOV = 240 × 240 mm; slice thickness = 5 mm; total volume = 240. DTI: TR/TE = 6,800 ms/93 ms; FOV = 240 × 240 mm; matrix size = 128 × 128; slice thickness = 3 mm; two diffusion-weighted sequences with $b = 1000 s/mm^2$ and $b = 0$ across 30 non-collinear directions.

Statistical methods

A detailed statistical plan, including data requirements and processing methods, will be provided to the statisticians by the research team before data analysis. Statisticians, independent and blinded to the test settings, will execute the analysis as per this plan.

Behavioral analysis

Data analysis will be conducted by an independent statistician using SPSS version 26.0 (SPSS Inc., Chicago, IL, United States). Two-tailed analyzes will be performed, with statistical significance set at $p < 0.05$.

Intention-to-treat analyzes will be applied wherever possible, complemented by subgroup and sensitivity analyzes to identify potential heterogeneity in results. Continuous variables will be expressed as means ± standard deviations, while categorical variables will be presented as numbers and percentages. The normality of continuous variables will be assessed using the Kolmogorov–Smirnov test. For normally distributed data, within-group differences will be evaluated using paired-sample t-tests, and between-group analyzes will employ Analysis of Variance (ANOVA) and the Kruskal–Wallis test. Non-parametric tests will be used for data with skewed distributions.

Neuroimaging data analysis

The fMRI data will be conducted pre-processing in accordance with SPM12[1] and MATLAB 2013b (MathWorks, Inc., Natick, MA, United States).

Data preprocessing will include discarding the first 5 time-points due to magnetic saturation effects, slice timing, head-motion correction, spatial normalization in Montreal Neurological Institute (MNI) space (resampled at 3 mm × 3 mm × 3 mm voxel size), filtering, and spatial smoothing with an 8-mm FWHM Gaussian kernel.

After preprocessing, the amplitude of low-frequency fluctuation (ALFF), fractional ALFF (fALFF), regional homogeneity (ReHo), functional connectivity (FC), and other brain functional parameters will be analyzed. The 3D-T1 data will be processed using voxel-based morphometry in SPM12 and the CAT12 toolbox in MATLAB (Ashburner and Friston, 2000). DTI data will undergo preprocessing and analysis with the Functional Software Library v4.1.9.[2] Fractional anisotropy (FA) indices and mean diffusivity (MD) maps will be derived after correcting for head motion and eddy currents in DTI images, followed by tensor model fitting. Correlation analyzes will involve Pearson correlation coefficients between clinical and fMRI data, primarily focusing on functional and structural changes in brain regions associated with emotions, attention, motor skills, and sensory perception.

Discussion

This study represents the first exploration into the patterns and mechanisms associated with Qigong practice among acupuncturists. Its outcomes will contribute initial insights into the effects of Qigong on emotional and attention control while revealing neuroimaging mechanisms unique to acupuncturists. Additionally, these findings will provide empirical support for integrating Qigong into strategies aimed at enhancing acupuncturists' skills.

Clinical trial quality control

This study will implement rigorous procedures to mitigate bias and enhance the reliability and reproducibility of the results.

To ensure uniform baseline results among subjects, strict screening and inclusion criteria have been established. Participants must be professionals with completed and verified theoretical and practical training in acupuncture. They should not have engaged in traditional fitness Qigong exercises (such as Baduanjin and Taiji) or mind–body practices (such as yoga and meditation) recently or previously.

For the Baduanjin and aerobic exercise groups, we have defined standardized training protocols, including specific movements, duration, and frequency. Experienced coaches (with over 5 years of practice) will supervise these sessions to guarantee consistency. Training sessions will be video recorded, and random assessments will be conducted to ensure adherence to established standards. The roles of researchers, operators, and statisticians have been distinctly defined, with professional statisticians undergoing specialized training prior to data analysis.

To maintain protocol adherence for all researchers to the study protocol, weekly group meetings will be held for effective communication and continuous learning. After the trial, participants will receive activity credit certificates and reimbursement. Any challenges encountered during the trial will be addressed promptly during these meetings.

Quality control of imaging tests

In this study, participants aged between 18 and 25 years and who are right-handed will be selected to minimize confounding effects on brain function and structure related to age and handedness. In addition, all neuroimaging scans will be conducted using the same scanner operated by an expert professional.

Before scanning, subjects will receive comprehensive information about the process and environment, along with an emotional assessment. They will be advised to avoid excessive exercise, late nights, and the consumption of alcohol, tobacco, tea, and coffee for 3 days before the scan. During the scan, subjects will wear sponge earplugs and have foam padding around their heads to limit movement. They will be instructed to keep their eyes closed but remain awake. The scanning room will be maintained at 18°C–22°C with humidity above 60% and noise levels below 150 dB.P After the scan, the data will undergo thorough review by professionals, and any data affected by artifacts, signal loss, distortion, or noise interference due to head movement will be excluded from the analysis.

Limitations

This trial faces several potential limitations. Firstly, due to the nature of the intervention, neither participants nor sports trainers can be blinded. While psychological outcomes are based on self-reports,

1 http://www.fil.ion.ucl.ac.uk/spm
2 http://fsl.fmrib.ox.ac.uk/fsl/fslwiki/TBSS/

assessments of hand function and imaging data will be conducted under blinded conditions. Secondly, the study's single-university setting, a result of funding constraints, may limit the representativeness of the results. Thirdly, although the intervention spans 24 weeks, this duration does not fully capture the long-term effects of Qigong practice on acupuncturists, indicating the need for future multi-center, large-sample randomized controlled studies.

Ethics statement

The studies involving humans were approved by Sichuan Regional Ethics Review Committee on Traditional Chinese Medicine. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

WL: Writing – original draft, Writing – review & editing. JZ: Writing – original draft, Writing – review & editing. XZ: Methodology, Writing – review & editing. YT: Validation, Writing – review & editing. ST: Investigation, Writing – review & editing. NC: Investigation, Writing – review & editing. DT: Data curation, Writing – review & editing. PS: Supervision, Writing – review & editing. KY: Methodology, Supervision, Writing – review & editing. ZL: Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Effects of self-efficacy on frontal midline theta power and golf putting performance

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Introduction: Self-efficacy (SE), defined as an individual's belief in their ability to complete a task, is linked to top-down attentional control, influencing motor performance in sports. Although the behavioral effects of SE are well-documented, there is a lack of research on the mechanisms through which SE affects sports performance. Our research aims to elucidate the neurophysiological mechanisms that underlie the impact of self-efficacy on sports performance. Specifically, we intend to explore the effects of low and high SE on frontal midline theta (Fmθ) activity, associated with sustained top-down attention, and on motor performance.

Methods: We recruited thirty-four professional golfers to perform 60 putts, during which their electroencephalographic activity was monitored. SE levels were assessed using a visual analog scale from 0 to 10 before each putt, with scores categorized into higher or lower SE based on each golfer's individual average score.

Results: Paired *t*-tests indicated that trials with higher SE scores had a higher putting success rate than those with lower SE scores (53.3% vs. 46.7%). Furthermore, trials associated with higher SE scores exhibited lower Fmθ activity compared to those with lower SE scores (4.49 vs. 5.18).

Discussion: Our results suggest that higher SE is associated with reduced top-down attentional control, leading to improved putting performance. These findings support Bandura's theory of SE, which suggests that the effects of efficacy beliefs are mediated by cognitive, motivational, emotional, and decision-making processes. This study sheds light on the intermediate processes of SE by examining its impact on the anticipation of outcomes, sports performance, and attentional control prior to putting.

KEYWORDS

self-efficacy, frontal midline theta, attention, sports performance, golf-putting

Highlights

- Identifying the cognitive-motor processes of superior performance can provide crucial information not only for accelerating the motor learning process but also for enhancing motor performance.
- Putting with higher SE was followed by less top-down attentional control, a characteristic of automatic processing, leading to better putting performance.
- Our findings support Bandura's SE theory, which posits that processes by which efficacy beliefs produce their effects are mediated by cognitive, motivational, emotional, and selection processes.

- The findings indicate that attentional control is a potential mediator of the relationship between SE and sports performance.

1 Introduction

Self-efficacy (SE) refers to individuals' belief in their abilities to complete a task or master a situation successfully (Bandura, 1997). In addition, SE can be considered situationally specific self-confidence, especially in sports (Feltz, 1988, 2007). Previous studies have recognized SE as a main determinant of successful performance (Moritz et al., 2000). Theoretical studies and meta-analyses have determined a strong relationship between SE and sports performance. For example, a meta-analysis of 41 studies demonstrated a moderate correlation between SE and sports performance, with an average correlation coefficient of 0.25 (95% confidence interval [CI]: 0.19, 0.30); the studies analyzed had minimal evidence of publication bias (Lochbaum et al., 2022). In addition, empirical studies have indicated that SE resulting from the successful practice of a motor task predicts performance on subsequent motor learning tests (Stevens et al., 2012; Pascua et al., 2015). The increased expectations of learners regarding their future successful performance can lead to even greater success, improvement, and learning (Rosenqvist and Skans, 2015). Moreover, compared with other psychological factors, SE can more effectively predict performance in high-level competitions (Ercis, 2018).

SE theory assumes that SE exerts a positive and significant effect on the performance of athletes. According to this theory, the mechanisms underlying the effects of efficacy beliefs or perceptions regarding SE on the outcomes of interest may be mediated by cognitive, motivational, emotional, and selection processes (Bandura, 1997). Various studies have demonstrated that higher SE can affect attention priming and prioritization, leading to increased attention to task-relevant cues and decreased attention to less relevant clues (Themanson and Rosen, 2015). Studies have identified an association of higher SE with increased attention to task error cues (Themanson et al., 2008) as well as higher response accuracy and faster reaction time during more difficult or incongruent task conditions (Themanson and Rosen, 2015). When action is planned and executed, higher performance expectancy may act as a buffer or protect against responses that would hinder optimal performance, such as nonbeneficial alternate responses, including off-task activities (Jiao et al., 2015; Zahodne et al., 2015). However, limited empirical studies have genuinely tested the theory (Lippke, 2020), especially the intermediate processes, such as cognitive, motivational, emotional, and selection processes, through which SE affects performance. Interestingly, most of the aforementioned studies have focused only on performance in cognitive tasks. The findings from these studies may not be generalizable to sports performance, as the required task success rates and movement patterns may differ.

Preaction top–down attentional control may play a key role in the relationship between SE and sports performance. According to the OPTIMAL (Optimizing Performance through Intrinsic Motivation and Attention for Learning) theory (Wulf and Lewthwaite, 2016), it explains the mechanisms underlying the association of SE with sports performance. This theory proposes that enhanced performance expectancy and prevented or reduced self-focus (or other off-task activity) contribute to effective goal-action coupling by preparing the motor system for task execution (Wulf and Lewthwaite, 2016; Lewthwaite and Wulf, 2017). High performance expectations appear to prepare the performer for successful movements through their impacts on attention and cognition, thus ensuring that objectives are effectively aligned with desired actions. However, the neurophysiological mechanisms underlying the association between SE with sports performance remain unclear. Therefore, identifying attentional control during preaction can provide critical information for optimizing performance and the benefits of SE.

Research in the field of motor performance has indicated that skilled performance can be "defined by high levels of automaticity, minimum energy expenditure, and reduced movement times" (Schmidt and Lee, 2014; Vickers and Williams, 2017, p. 5; Filho et al., 2021). An number of neuroscience studies recently have used electroencephalography, which can provide a high temporal resolution of neural activity, to investigate and identify the neurophysiological processes underlying athletic performance. For example, recent research in self-paced sports observed a significant decrease in Fmθ activity in experts compared to novices (Filho et al., 2021). Although athletes need to engage and disengage different areas of their brains to perform at optimal levels (i.e., brain proficiency), their frontal lobe works at the lowest rate possible (i.e., transient hypofrontality), which may explain the reported feelings of automaticity, control, confidence, and relaxation experienced by skilled performers when performing at optimal levels (Williams and Krane, 2020). This preaction hypofrontality (lower Fmθ) indicates decreased attention and working memory, which easily facilitate automatic actions (Dietrich et al., 2003; Dietrich, 2006) and sport performance in experts (Chen et al., 2022). The hypofrontality phenomenon may illustrate the process through which SE improves sports performance and explain the relationship between SE and changes in attention. Specifically, higher self-efficacy (SE) may influence pre-action attentional regulation, as suggested by Themanson and Rosen (2015), with decreased Fmθ brain activity being linked to sport performance. Consequently, Fmθ brain activity could act as a precise indicator for clarifying the mechanisms through which SE impacts sports performance.

Integrating the above theories, the OPTIMAL theory of sports performance can be supported by the principles of Self-Efficacy (SE) theory (Bandura, 1997; Themanson and Rosen, 2015). SE may enhance sports performance by enhancing expectations of outcomes, integrating goals and actions through prioritized attention, and inhibiting attention to less relevant task (as depicted in Figure 1). However, research on the neurophysiological mechanisms underlying the SE effects of sports performance is sparse. To provide new insights into the neurophysiological mechanisms underlying the effects of SE on sports performance, the present study utilized EEG and investigated the effect of low and high SE on Fmθ activity that involves with top–down sustained attention and on the motor performance in skilled golfers. To facilitate EEG recording, we utilized a golf putting task that necessitates maintaining motionlessness during data collection (Wang et al., 2019, 2020). Considering that individuals with high SE may possess automatic characteristics, such as reduced top–down attentional control and working memory (as depicted in Figure 1), leading to

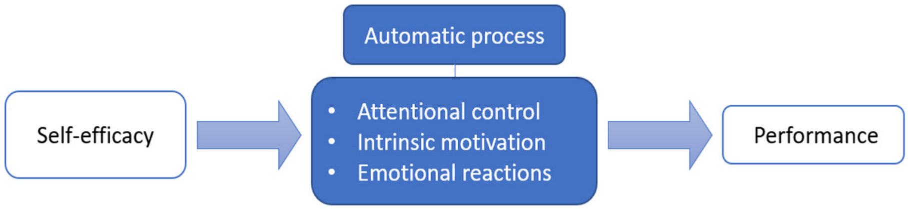

FIGURE 1
Conceptual framework.

improved motor performance, we hypothesize that higher SE is associated with enhanced golf-putting performance and lower Fmθ power.

2 Methods

2.1 Participants

The study follows a Cross-sectional design, 34 right-handed professional male golfers were recruited from the Greater Taipei area between August 2020 and July 2021. The age of these golfers ranged from 23 to 60 (mean age = 42.2 ± 10.4) years, and they had a mean experience of 11.2 (standard deviation [SD] = 7.3) years playing golf and a mean handicap score of 16.4 (SD = 7.2). According to United States Golf Association (USGA) statistics, a handicap score of 15 reflects golf skills above 42.58% of male golfers (United States Golf Association, 2024). The sample size was determined based on an a priori power analysis using G*Power 3.1. Consistent with a previous electroencephalography study on attentional instruction (Hunt et al., 2013), we set the following input parameters for a paired *t* test: alpha = 0.05, power = 0.80, effect size = 0.33–0.50 (corresponding to ηP^2 = 0.10–0.20), and actual power = 0.80. We determined the sample size of 34 for this study.

All the recruited participants met the following inclusion criteria: (1) no history of neurological diseases and (2) right-handed. All the participants provided an informed written consent. This study was approved by the Research Ethics Committee of National Taiwan Normal University (201912HM109). All study procedures were carried out in accordance with the relevant guidelines and regulations of the research ethics committee.

2.2 Procedure

Participants are required to come to the experiment once and are asked not to consume any beverages containing alcohol or caffeine within 24 hours prior to the test. Upon arriving at the laboratory, written informed consent was obtained from the participants. The participants were then fitted with a Lycra electrode cap (Quick-cap, Neuroscan, Charlotte, NC, USA), and impedance and signals were examined. The resting-state EEG data of the participants were recorded first, followed by a minimum of 12 putting practice trials prior to the formal putting task. EEG signals were recorded during the golf-putting task that consisted of 60 self-paced trials, which were divided into six recording blocks (10 putts per block with an interblock interval of ∼2 min). The total duration of the experiment was ∼2 h.

2.3 Measurements

2.3.1 Golf-putting task

The participants performed a putting task on an indoor artificial golf green with a length of 572 cm and a width of 200 cm. The hole diameter conformed to the standard size (10.8 cm). The distance between the starting point and the hole was 3 m. During an official competition, a golfer's primary goal is to let the ball roll into the hole. Professional golfers, on average, have a one-put probability (success rate) of 40% when they put the ball from a distance of 3 m during the Professional Golfers' Association Tour. This distance determines the results of a golf game due to its medium difficulty. To simulate an actual match, serial variable practice was used by instructing participants to putt from three starting lines at their own pace. Their objective was to let the ball roll into the hole. The task variability was increased to enhance the participants' engagement in the task. A successful putt was defined as the ball rolling into the hole, whereas a failed putt was defined as the ball not rolling into the hole.

2.3.2 SE

For self-efficacy assessment, we used a modified scale based on Turner et al. (2008).

Specifically, participants were requested to their confidence level on a visual analog scale (VAS) ranging from 0 to 10 before each putt, where 0 indicated "not confident at all" and 10 indicated "completely confident". These were of the form: indicate how confident you believe yourself to be putting task. The advantages of this method are as follows: (1) the psychometric properties of the VAS have received substantial support in previous research (Davey et al., 2007; Hunt et al., 2013) and (2) the VAS can be completed more rapidly and thus reduces interference for participants (Watkins et al., 1994). Based on the median score, individual SE scale scores were classified as high or low SE trials.

2.3.3 Electroencephalography recording and analysis

During the putting task, electroencephalographic (EEG) activity was recorded at 32 sites by using an elastic electrode cap (Quick-Cap, Compumedics Neuroscan, Inc., Charlotte, NC, USA) in accordance with a modified International 10–20 System.

Ongoing EEG activity was referenced to the average of the mastoids (A1 and A2), with FPz serving as the ground electrode. Electrooculographic (EOG) activity was recorded using four electrodes placed at the outer canthus of each eye and above and below the left orbit. EEG and EOG signals were recorded using NeuroScan NuAmps software, version 4.5 (Neuroscan), with the bandpass filter ranging from DC to 100 Hz and the notch filter set at 60 Hz. The signals were sampled at a frequency of 1,000 Hz, and the electrode site impedance was maintained below 10 kΩ. Prior to assessing performance, event marker data were collected using an infrared sensor that detected the onset of each putt swing to understand the preparation state (Chen et al., 2022; Wang et al., 2022; Chueh et al., 2023). The swing onset was defined as the event when the participants moved the putter away from the ball to initiate a backswing.

EEG data were processed using EEGLAB software on MATLAB (Delorme and Makeig, 2004). During data processing, EEG signals were filtered using an FIR filter with its digital bandpass ranging from 1 to 50 Hz (6 dB/octave). To focus the independent component analysis (ICA) computation on task-related activity, data exceeding 2 s before and after the event marker were removed. ICA decompositions were performed using the infomax algorithm with default settings in EEGLAB to extract sub-Gaussian components (Bell and Sejnowski, 1995). Subsequently, the icablinkmetrics function (version 3.1) was utilized to eliminate ICA components related to eyeblink artifacts, and EEG signals were reconstructed without these artifacts (Pontifex et al., 2017). The average numbers of IC were excluded (2.68 ± 1.69). Continuous EEG data was then segmented and extracted for a preparatory period of 2 seconds immediately preceding the swing onset for further analysis.

Epochs with amplitudes outside the range of ±150 μV were discarded. The average numbers of bad trial rejected were similar for all the conditions (High-SE =3.68 ± 7.33 and Low-SE = 2.63 ± 6.12).

Artifact-free epochs were fast Fourier transformed with a Hamming window to compute the power spectral density (PSD) of each frequency band with a 0.5-Hz bin. For electrodes, the PSD values of the following regions of interest were averaged: F3, Fz, and F4. The θ power was extracted from the data in the 4–7.5Hz range and The Alpha power was extracted from the data in the 8-13 Hz range. The EEG power data were then naturally log-transformed (ln), as they violated the Shapiro–Wilk normality test ($p < 0.05$). Performance-related EEG data were analyzed using a previously reported procedure (Chueh et al., 2023).

2.4 Statistical analysis

Data were organized and transformed (such as addition, subtraction, and average) using Excel. SPSS (version 23) was used to perform all statistical analyses. Means and SDs were calculated for all data. Based on the median scores of individual SE, each trial was classified into either a high SE trial or a low SE trial. This research applied a separate paired t-test to evaluate the variances in putting success rates and Fmθ across trials with high self-efficacy (SE) and low SE, under the condition that SE, putting success rates, and Fmθ are unrelated. we evaluated the degree of correlation among these three variables. Should there be any correlation, the method will be adjusted to employ ANCOVA. The *t* test was chosen over multiple-factor analysis of variance (ANOVA) to reduce the inflation of type I error from the factors (familywise type I error) (Luck and Gaspelin, 2017, p. 9–11). The α level was set at 0.05, and the effect size was reported as dmatched (Cohen, 2013, p. 351), along with a 95% CI (Moher et al., 2010, Item 17a).

In a control analysis, to determine the task specificity of Fθ in the golf-putting task, ANOVA was used to examine differences in Fθ across different brain regions (FZ, PZ, and CZ). Furthermore, in case of significant findings, a *post hoc* analysis was performed to estimate effect sizes using partial η2 and Cohen's d (for the equation, see Dunlap et al., 1996). In addition, Alpha power has been demonstrated to be a key indicator of focus and engagement, not just in controlled laboratory settings but also when using portable EEG technologies (Arnau et al., 2021). It's crucial to conduct further control analyses to ascertain that the variations observed are, in fact, primarily influenced by theta wave activity.

TABLE 1 Summary of behavioral and EEG outcomes.

	Total	High-SE	Low-SE
Putting success rate (%)	50.68 (15.10)	53.32 (17.18)	46.86 (16.96)
SE (scales)	7.99 (1.31)	8.57 (1.27)	7.12 (1.58)
SE trials (/60 trials)	60 (0)	34.5 (12.5)	25.4 (12.4)
Fmθ (μV)	4.85 (4.16)	4.49 (3.93)	5.18 (4.74)
FmAlpha (μV)	2.74 (1.61)	2.66 (1.65)	2.77 (1.69)

3 Results

1. A two-pair *t* test (high-SE vs low-SE) was performed to investigate variations in the putting success rate and Fmθ prior to the execution of the putting task. The demographic factors, putting success rate, and EEG findings are listed in Table 1. To rule out some potential competing explanations, we determined the correlation between θ power at Fz and the putting success rate.
2. Putting performance: the mean putting success rate of all the participants was 50.7% ± 15.1%. The putting success rate significantly differed between the high- and low-SE conditions, $t_{(33)} = 2.97$, $p < 0.01$, with the success rate being higher in the high-SE condition than in the low-SE condition. (53.3% > 46.7%).
3. EEG power: the Fmθ value significantly differed between the high- and low-SE conditions, $t_{(33)} = -2.37$, $p < 0.05$, with the Fmθ value being lower in the high-SE condition than in the low-SE condition (4.49 < 5.18) (Figure 2).
4. Control analysis: to check the task specificity of θ in the golf-putting task, ANOVA was used to examine differences (HSE - LSE) in θ across different brain regions (Fz, Cz, and Pz). The ANOVA showed a significant effect of brain regions in θ power, $F_{(1,32)} = 3.77$, $p = 0.034$, $\eta_p^2 = 0.19$, with Fz (−0.61 ± 0.41) having larger differences than Cz (−0.14 ± 0.17) and Pz (−0.14 ± 0.11).

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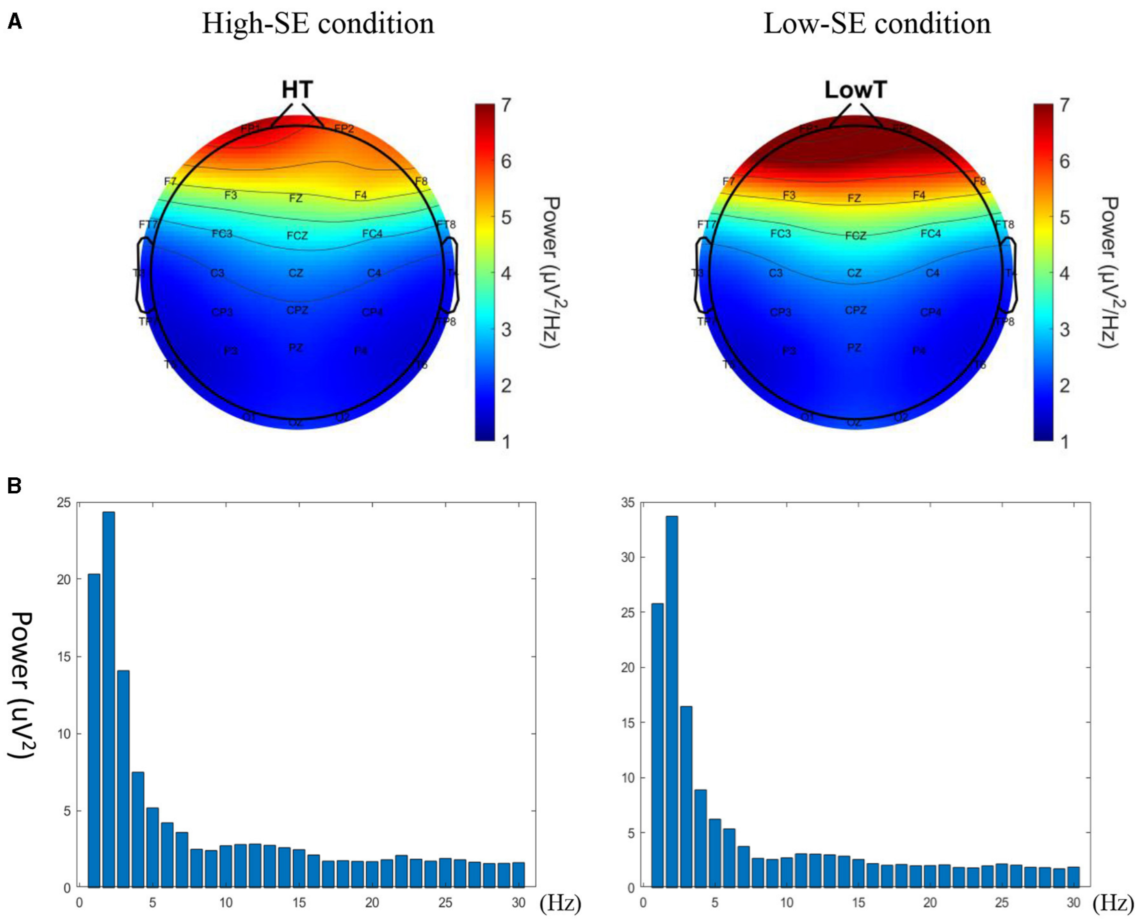

FIGURE 2
(A) θ power between high- and low-SE conditions. **(B)** Power spectrum at Fz between high- and low-SE conditions.

On the other hand, the Alpha values in both high-SE and low-SE conditions are depicted in Figure 3, yet there are no differences between these conditions. By the side, we didn't find any correlation between θ power at Fz, SE, experience year and the putting success rate.

4 Discussion

This study employed electroencephalography to investigate the effect of low and high SE on frontal midline theta and the motor performance. We compared putting performance and EEG power during the preparatory period of a putting task in skilled golfers with high and low SE levels. We observed that the golfers' putting success rate was higher and Fmθ power was lower in higher SE trials.

The results of this study support our hypothesis that golfers with a higher SE score have a higher success rate. This result is consistent with those reported by Chang et al. (2014) and Horcajo et al. (2022). Horcajo et al. (2022) showed that SE was positively related to both physical and cognitive performance. Chang et al. (2014) determined a significant positive correlation between SE and softball throwing performance. To explain the positive relationship between SE and motor performance, Bandura (1990) defined SE as an individual's sense of confidence in their ability to perform a given behavior in various contexts. Bandura described SE as a cognitive mechanism that mediates the relationship between self-appraisal information and an individual's subsequent thoughts, emotions, motivations, and behaviors. SE theory posits that people are more likely to engage in behaviors that they believe they can successfully perform and avoid behaviors in which they feel they will be unsuccessful.

Studies have indicated that self-efficacy (SE) is closely linked with a variety of mechanisms, including cognitive functions, motivation, emotions, and selection processes. Specifically, within the realm of selection processes, research has identified a correlation between SE and cognitive functions, notably in decision-making scenarios. This connection is evident in the realm of sports, where SE has been found to significantly influence decision-making abilities in baseball players, as noted by Hepler and Feltz (2012). Furthermore, from a behavioral perspective, individuals possessing higher levels of SE are more inclined to pursue ambitious goals, as outlined by Bandura (1997), and exhibit superior self-regulation skills (Kane et al., 1996). Considering the impact of factors related to SE, such as decision-making capabilities, goal-setting, self-regulation, and anxiety management,

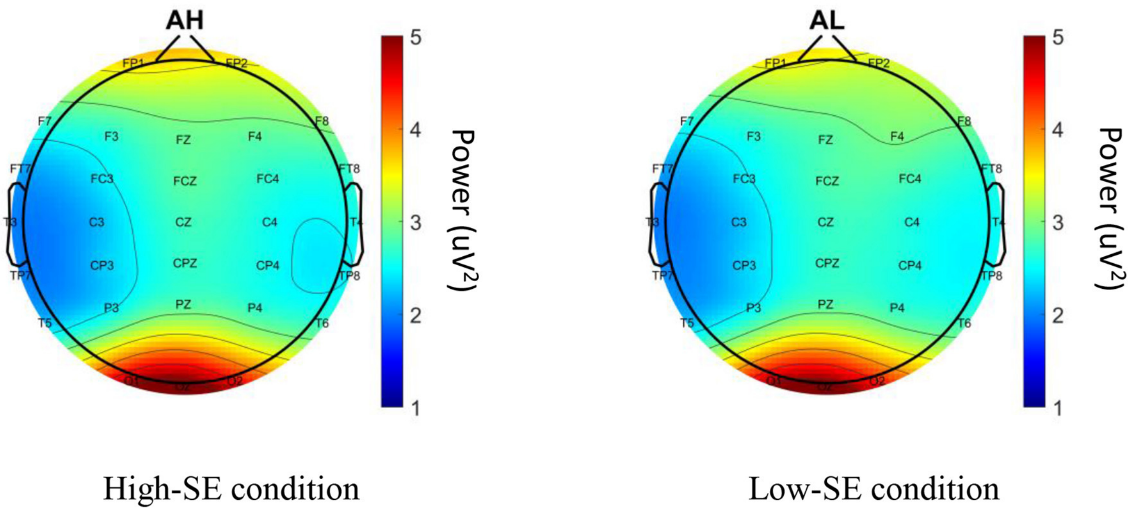

FIGURE 3
Difference in Alpha power between high- and low-SE conditions.

on overall performance, SE emerges as a critical factor for achieving excellence. This has led to its recognition as a key predictor of successful outcomes in various fields (Moritz et al., 2000). The collective body of research underscores the integral role of SE in fostering a framework for individuals to excel, by enhancing their psychological resilience and operational efficiency.

Another primary finding of this study is that the golfers exhibited lower Fmθ power in high-SE trials, supporting the hypothesis that higher SE leads to more automatic processing during golf-putting tasks. This finding is consistent with that of a previous study indicating that individuals with a lower confidence level exhibited increased prefrontal brain activity on functional magnetic resonance imaging (Fleming et al., 2012). Moreover, Hunt et al. (2013) found that the winning group in a shooting competition exhibited a higher confidence level and lower alpha and theta power than the losing group. In contrast, Chatterjee et al. (2021) found higher theta and alpha power in the frontal cortex in high-confidence conditions than in low-confidence conditions; cognitive experiments showed that higher SE is associated with a stronger deployment of attentional control (Frömer et al., 2021). However, it is important to note that the latter study did not specifically examine sports performance. These findings collectively underscore the potential of Fmθ power as a critical intermediary in the complex interplay between SE and athletic performance. The consistency across these studies suggests that SE not only affects psychological states but also has a tangible impact on physiological responses during competitive sports. This underscores the importance of developing strategies to boost athletes' confidence as a means to improve their focus, reduce unnecessary cognitive load, and enhance overall performance.

This study used EEG evidence to determine sports performance, focusing on the expert paradigm in self-paced, precision sports. A previous meta-analysis indicated a nonsignificant increase in alpha activity and a decrease in theta activity in this context (Filho et al., 2021). The "relaxed brain" neural marker is characterized by increased alpha activity across the cortex, which inhibits brain areas unrelated to the task at hand, particularly in the frontal lobe where the highest alpha and lowest theta activity are found (Filho et al., 2021). These findings support those of previous studies demonstrating that a relaxed and focused brain is essential for optimal sports performance (Pacheco, 2016; Bertollo et al., 2020; Hatfield et al., 2020). Although theta activity may indicate the need and timing of cognitive control, it may not necessarily play a functional role in downstream signaling. Experienced performers can enhance their motor skills by suppressing irrelevant cognitive and motor processes; this phenomenon is known as neuromotor noise. The brain needs to integrate cognitive control processes into sensorimotor systems to achieve behavioral control. The suppression of neuromotor noise is a crucial factor in the development of enhanced motor skills, and frontal theta is involved in sensorimotor integration (Cruikshank et al., 2012). Thus, the findings of this study indicated that SE affects the electrophysiological state of the brain, leading to more automated actions.

Our findings support and extend Bandura's SE theory by demonstrating that the anticipation of outcomes may affect the automation of actions and that Fmθ power may mediate the relationship between SE and sports performance. Optimal sports performance is characterized by a constant focus on the present as well as physical and psychological relaxation, which enable effortless automatic movements. Fmθ is among the most crucial elements of optimal sports performance (Williams and Krane, 2020).

Fmθ power measures attentional allocation to achieve a desired cognitive–motor behavior, particularly as measured from the anterior region of the scalp, and is indicative of task-relevant working memory processes (Jensen and Tesche, 2002; Sauseng et al., 2010). Studies have suggested that cognitive control originates in the frontal cortex and is mediated by cortical oscillations that underlie long-range communication in the brain (Buzsáki et al., 2012; Cavanagh and Frank, 2014). The level of Fmθ was proportional to the degree of effort invested in response inhibition and preparation (Isabella et al., 2019). Frontal theta oscillations might be involved in physiological mechanisms underlying cognitive control because they increase during working memory (Jensen and Tesche, 2002; Zakrzewska and Brzezicka, 2014), mental arithmetic (Gärtner et al., 2015), response preparation (Womelsdorf et al., 2010), affective regulation (Cavanagh and Shackman, 2015), top–down attention (Cavanagh and Frank, 2014). A lower level of Fmθ may suggest that golfers were not engaged in active mental control during the putting task. This speculation is supported by two previous studies (Kao et al., 2013, 2014), which have reported that superior putting performance was preceded by a lower level of Fmθ (Kao et al., 2013) and that one neurofeedback training session on reducing Fmθ power effectively improved the putting performance of highly skilled golfers (Kao et al., 2014). Individuals with elevated levels of SE often lean toward their first, instinctive reactions, considering fewer options in the process. To achieve behavioral control, the brain integrates cognitive control processes into sensorimotor systems (Hepler and Feltz, 2012). The modulation of behavioral responses through cognitive regulation is frequently accompanied by theta-band activity in the frontal cortex, where Fmθ power serves as an indicator of attentional allocation toward achieving desired cognitive–motor responses (Sauseng et al., 2010). SE, as established through the prediction of consequences, might influence the automatization of actions and Fmθ power before the act of putting, thus potentially mediating the association between SE and sports performance.

Although this study using the VAS method yielded novel insights into the putting performance of golfers based on EEG findings, it is not without limitations. Firstly, factors such as learning, fatigue, and variable practice may affect putting performance. Thus, future studies should consider incorporating relevant subjective measurements such as self-report, VAS when designing their experiments. Nevertheless, we addressed some of these limitations by providing an opportunity for practice before the primary task, including a 2-minute rest period between blocks, and setting three starting lines for putting (serial variable practice). However, the additional analysis indicated no significant difference [$t\,(26) = -0.815$, $p = 0.422$] in the putting success rate between the first and last three blocks was observed. We suggested that these factors exerted only a negligible impact on putting performance in this study. Secondly, this study employed a putting task at a distance of 3 m, with medium difficulty, and categorized performance into binary variables (i.e., successful and unsuccessful putt) based on the reality of golf games and the purpose of this study. Future studies should consider using a longer distance (e.g., professional golfers' average two putts from 33 feet, see Broadie, 2012) for the putting task and measure performance outcomes as continuous variables, such as the radial error (i.e., the distance between the hole and ball), to gain a more comprehensive understanding of the cortical signatures of superior performance.

To summarize, this study contributes to understanding of the neurophysiological mechanisms underlying the effects of SE on sports performance and extends to SE theory (Bandura, 1997; Moritz et al., 2000). SE determined by the anticipation of outcomes, may influences the automation of movements and the activity of frontal midline theta (Fmθ) power before executing a putting action. This relationship highlights SE's role in bridging cognitive expectations with physical performance in sports, emphasizing how psychological Self-efficacy could shape sport performance and execution efficiency. Moreover, our findings indicate that higher individual SE is associated with improved putting performance and greater automation characteristics in golfers. Therefore, enhancing SE before putting can be a promising strategy for improving overall sports performance in golfers.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: This study was not preregistered. All data and measures used in the study are publicly available under the Open Science Framework (https://osf.io/x5vsg).

Ethics statement

This study was approved by the Research Ethics Committee of National Taiwan Normal University (201912HM109). All study procedures were carried out in accordance with the relevant guidelines and regulations of the research ethics committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

C-LY: Writing – original draft, Visualization, Project administration. C-WK: Writing – original draft, Data curation, Conceptualization. J-HW: Writing – review & editing, Methodology, Formal analysis. EH: Writing – review & editing, Investigation, Data curation. W-CC: Writing – review & editing, Project administration, Data curation. R-TY: Writing – review & editing, Project administration, Data curation. K-PW: Writing – review & editing, Supervision, Conceptualization. T-MH: Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Profile of gym-goers who do not use performance-enhancement substances

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Introduction: Currently the use of prohibited performance-enhancing substances (PES) in fitness and gym settings is a public health concern as adverse health consequences are emerging. Understanding the characteristics of gym-goers who do not use these substances could lead to an important complement to the ongoing research about risk factors for PES use. The aim of this study was to identify the profile of PES non-use in gym-goers.

Methods: In total, 453 gym-goers (mean age = 35.64 years; SD = 13.08 – measure of central tendency location and measure of absolute dispersion, respectively) completed an online survey assessing sociodemographic factors, exercise characteristics, gym modalities, peers, social influence, attitudes, subjective norms, beliefs, intentions, and self-reported use of PES.

Results: Decision Trees showed that being a woman, training less frequently, not practicing bodybuilding and having a negative intention to consume PES were identified as characteristics of non-users of PES.

Discussion: These results may support evidence-based anti-doping interventions to prevent abusive use of PES in the fitness context.

KEYWORDS
gym-goers, characteristic, behavior intentions, decision trees, doping, substance use

1 Introduction

The research on psychosocial factors associated with the consumption of prohibited performance-enhancing substances (PES) in sports, physical activity, and fitness has increased over the past 20 years (e.g., Wiefferink et al., 2008; Morente-Sánchez and Zabala, 2013; Ntoumanis et al., 2014; Tavares et al., 2019a). Researchers' interest in this area may be attributed to the prevalence rates of prohibited substance [e.g., anabolic-androgenic steroids (AAS), stimulants, erythropoietin (EPO), human growth hormone, and diuretics] use, which was shown to be as high as 73% in competitive sports (Gleaves et al., 2021), and 70% in the fitness context (Tavares et al., 2019a). Moreover, the media impact of cases involving performance-enhancing substance use in major global sports competitions, such as the Olympic Games (Associated Press/NBC, 2022) or the FIFA World Cup (Bubel, 2023), further contributes to the attention this topic has received.

While specific regulations and a publication of a list of prohibited substances by the World Anti-Doping Agency (WADA) exist for professional sports contexts to inform and control behavior associated with PES use, only a few countries have legal procedures for controlling fitness participants' substance use (Thualagant, 2012). This fact should be a concern for these substances have long-term physical and psychological consequences on individuals' health (Pope et al., 2014). To address this concern, this article will focus on the identification of the profile of gym-goers who do not engage in this risky behavior.

Researchers have been trying to understand and evaluate the psychological determinants of PES use by fitness participants (Elbe and Barkoukis, 2017). Studies have focused on attaining knowledge of predisposing factors influencing the decision to consume PES to influence consumption behavior and prevent such acts (Petróczi and Aidman, 2008). This is evident in the multitude of variables analyzed to assess determinants associated with PES use in fitness, such as participants' attitudes and judgments, beliefs about the outcomes or consequences, and social influences on engaging in PES use (e.g., Allahverdipour et al., 2012; Tavares et al., 2020a).

Although scientific evidence identifies a set of psychological and social determinants associated with PES use, including intentions, attitudes, and beliefs (e.g., Wiefferink et al., 2008; Tavares et al., 2020a), it is important to examine the reasons for non-use, that is, to identify the characteristics of those gym-goers who do not use PES. The identification of the profile of these individuals will help distinguish risk characteristics prone for PES use from preventive ones. Emphasizing the promotion of the latter factors rather than focusing on penalizing the use of PES by gym-goers might be an alternative strategy to promote a safe engagement in gym activities (Henning and Andreasson, 2022). The potential negative health impact of PES use and its increased prevalence in gym-goers (Lazuras et al., 2017; Tavares et al., 2020b), focusing on individuals' capacity to develop health assets that empower them to engage in health-protective behaviors (Morgan and Ziglio, 2007) requires an understanding of the profile of those who do not consider or refuse PES use.

Therefore, understanding the motivations of those gym-goers who reject PES, despite social pressure to consume (Copeland and Potwarka, 2016), may involve identifying a set of beliefs, attitudes, norms, and intentions, concerning substance use (Barkoukis et al., 2013). Following recent research that explained these cognitive aspects associated with PES use in the fitness context (Tavares et al., 2020a), the present study adopts the main concepts of the Theory of Planned Behavior (TPB; Ajzen and Fishbein, 1980; Ajzen, 1991) to explain the determinants of non-use of PES.

Over the past years, researchers have found that athletes' substance use is determined by their intentions to engage in behaviors aimed at improving performance (e.g., Barkoukis et al., 2013; Ntoumanis et al., 2014). According to researchers who have conducted studies based on TPB (e.g., Chan et al., 2015a; Kirby et al., 2016), these intentions for PES use, in turn, are determined by three main social cognitive factors. First, they are influenced by athletes' attitudes toward substance use. Attitudes toward PES use depends on the beliefs about the outcomes of the behavior and the judgments about its personal consequences, that is, the costs and benefits associated with substance use, as well as the emotional value athletes attach to these consequences. Second, intentions are determined by the subjective norms related to substance use. Subjective norms represent individuals' perceptions of what their significant others believe they should do (normative beliefs) and whether they are motivated to act accordingly to those beliefs (motivation to comply) (Albarracín et al., 2001). Lastly, the perceived behavioral control (PBC) over PES consumption refers to one's beliefs about the barriers and the perceived power one exerts over those barriers. In addition to its influence on intentions, PBC also directly influences behaviors when individuals have incomplete control over the behavior (Martinez and Lewis, 2016).

The TPB framework has also been utilized to explain PES use in gym-goers. Allahverdipour et al. (2012) were able to predict 63% of the intention to use PES based on PBC, subjective norm and attitudes. However, intention was the only variable that predicted self-reported PES use. Based on TPB, Tavares et al. (2019b) conducted a validation study on the Questionnaire of Attitudes toward Doping in Fitness (QAD-FIT). The emerging factor structure resulted in an instrument that assesses four dimensions related to the psychosocial aspects of PES use within the context of fitness. These dimensions consisted of attitudes, subjective norms, beliefs, and intentions regarding PES use. Subjective norms were the strongest predictor of intentions, followed by beliefs and attitudes. The three variables predicted 75% of intentions to use PES, which in turn predicted 44% of PES use. Subjective norms as the strongest predictor supports the important role of perceived social norms; indeed, first-hand accounts of peers have been identified as a major source of information for anabolic steroids users in the gym population (Kimergård, 2015).

Some research has explored the reasons behind not using PES. In a large study that encompassed five European countries, the most frequent reasons for young adults not to engage in this behavior were worry about the negative health impact, not feeling the need to use them, and a desire to find out how much individuals can achieve on their own. Not being able to afford these substances or not having access to them were not generally important reasons for non-use (Lazuras et al., 2017). These results reinforce the need for educational practices that emphasize the development of individuals' empowerment.

In addition to these psychosocial determinants other demographic variables are likely to influence behavior. For example, being male, having lower educational qualifications, being unemployed, high training frequency and practicing bodybuilding were more likely to engage in PES compared to their counterparts (Tavares et al., 2022). A global profile of PES users further included "a desire to increase muscle mass, shape their body, and improve physical condition; being advised by friends, training colleagues and coaches or on the Internet" (p.10). Moreover, AAS male users demonstrated greater likelihood to meet criteria for substance dependence disorder, and reported having an anxiety disorder, frequent recent use of cocaine and a history of sexual abuse (Ip et al., 2011) when compared to their male non-user counterparts.

Considering the evidence that suggests the involvement of cognitive determinants in PES use (e.g., Wiefferink et al., 2008; Tavares et al., 2019a, 2020a), it is important to understand how these determinants can constitute protective factors in individuals who do not report use of PES. Therefore, the present study's main objective is to identify the profile of the non-use of PES of gym-goers. Accordingly, it is expected that unfavorable attitude toward substance consumption, the absence of a subjective norm that emphasizes consumption and, finally, unfavorable beliefs about the outcomes of PES consumption are associated with reports of non-use of PES. Additionally, it is also hypothesized that intentions toward PES use is negatively associated with self-reports of PES non-use. Finally, it is hypothesized that females and those who practice non-strength-based activities are more likely to report non-use of PES.

2 Materials and methods

2.1 Participants

Participants were 453 Portuguese gym-goers with ages ranging from 16 to 79 years (mean: 35.64; SD: 13.08), of both female (277; 61.1%) and male genders (175; 38.6%), and one did not indicate their gender (0.3%). Inclusion criteria included: practicing any gym activity, being older than 16 years of age, having capacity to read, and access to a smartphone, tablet, or PC to respond the online survey. To identify an appropriate sample size, we used an *a priori* sample size calculator (Soper, 2017). A sample of 434 participants were required to achieve a power of 0.90, and an anticipated effect size of 0.20 (meaning that the study has a 90% chance of detecting an association with the specified effect of 20%). The significance level was 0.05.

2.2 Measures

2.2.1 Self-reported use of PES

After responding "yes" or "no" to the question "As part of your practice, have you ever taken performance-enhancing substances?" two groups were formed according to their answers (users and non-users). We considered the WADA Prohibited List to define PES which excludes dietary supplements and vitamins (**Supplementary Appendix A**).

2.2.2 Questionnaire of attitudes toward doping in fitness

The QAD-FIT is composed by 16 items grouped into four dimensions based on the TPB: attitudes (five items; e.g., "Selling PES should be punished"), subjective norms (three items; e.g., "I would take PES, if most people I know approved of it"), beliefs (three items; e.g., "Performance enhancing substances help to improve physical abilities"), and intention (five items; e.g.; "I would take PES to achieve my goals in the practice of physical activity"). Answers to the questionnaire were given on a seven-point Likert-type scale where 1 corresponded to "totally disagree" and 7 to "totally agree." The total composite reliability (CR) for QAD-FIT was 0.85, with values of 0.74 for beliefs, 0.84 for attitudes, 0.86 for subjective norms, and 0.97 for intentions (Tavares et al., 2019b).

2.3 Procedures

Institutional e-mail and Facebook accounts of Lisbon fitness centers were used to advertise the research and recruit participants, between October and November 2017. Those who accepted to participate accessed the survey web link where a participant information and informed consent page was presented. Here, information regarding the study was given as well as the explanation concerning how anonymity and confidentiality were guaranteed. It was not possible for data to be traced back to individual participants or their Internet providers. Moreover, encryption was performed during data transfer. Demographic data, self-reported use of PES (doping behavior), and attitudes, subjective norms, beliefs, and PES use intention were collected using a web-based survey administered via REDCap software (Version 5.11.4, Vanderbilt University). Fifteen minutes was the approximate time needed to complete the questionnaire. Ethical approval for the study was obtained from the Ethical Committee of the University of Lisbon, Faculty of Human Kinetics (study protocol no. 38/2017).

2.4 Data analysis

Data were analyzed using SPSS V27.0 statistical software for Windows. Results were considered statistically significant at a significance level of 5%. To identify the profile of non-PES users, Decision Trees were used, which are a method widely used in classifying and identifying profiles, in machine-learning and data mining. The method used to create the nodes of the decision tree was CHAID, because in addition to qualitative variables the database also included quantitative variables. For the decision tree models, split-sample validation was considered, using random assignment, where 50% of the data were used for the training phase and the remaining 50% were used for the testing phase. The results presented are those of the test phase. To understand the relationship between beliefs, subjective norms, attitudes and intention, multiple linear regression analysis was used. The models obtained obey the Gauss–Markov conditions (residuals with zero mean, constant variance, and Normal distribution) and do not present multicollinearity between the independent variables, evaluated through the tolerance value (whereby values <0.1 indicate the existence of multicollinearity) and/or the VIF (values >10 suggest multicollinearity) (Pestana and Gageiro, 2014; Marôco, 2021).

3 Results

3.1 Sociodemographic characteristics

The use of PES was reported by 50 participants (11.1% of the 453 participants). Considering sociodemographic characteristics (gender, age, education, marital status, and occupation), only gender and age were significant, verifying that 94.5% of women do not consume PES. As far as men are concerned, 80% do not consume and those under 25 years old, 92.6% do not consume (**Figure 1**).

3.2 Activities, training frequency, and training time

The activities in which the participants were involved were cardio fitness (57%), recreational bodybuilding (56.5%), stretching

(27.8%), and localized gymnastics (27.2%). The frequency of training, bodybuilding and functional training were significant. Of those who have a lower training frequency (1, 2, or 3 times a week), 95.5% do not consume PES. Among these, 98.1% do not take PES and do not practice bodybuilding. Regarding those who have a higher training frequency (4 to 6 times, 7 or more times) and who practice functional training, 88% do not consume PES (**Figure 2**).

3.3 Psychosocial determinants

Regarding beliefs, subjective norms, intention, and attitudes, only intention proved to be the most important, with it being found that 97% of individuals who have a negative intention to consume PES (score ≤3.6) do not consume it (**Figure 3**).

Taking in account that only intentions was significant, the results of multiple linear regression analyzes are presented below. Attitudes, subjective norms, and beliefs proved to be predictors of intention (p < 0.0001 for all significant associations), verifying that higher scores on any of the three scales are related to higher intention scores (**Table 1**).

3.4 Global profile

Now considering the characteristics that proved to be significant in the previous models, namely age, gender, training frequency, bodybuilding, functional training, and intention, only intention, gender, and bodybuilding proved to be significant. Of those who have a negative intention for PES consumption, were women and do not practice bodybuilding, 100% do not consume PES (**Figure 4**).

4 Discussion

Research on doping and performance enhancement substances, both in competitive sport and in recreational fitness context have mostly focused on the population that consumes this type of products (Wiefferink et al., 2008; Tavares et al., 2020b; García-Grimau et al., 2021). Among these studies several of them have used the TPB to predict this kind of behaviors (Chan et al., 2015a; Kirby et al., 2016; Tavares et al., 2020a). However, as far as we know, no studies have been developed to investigate the

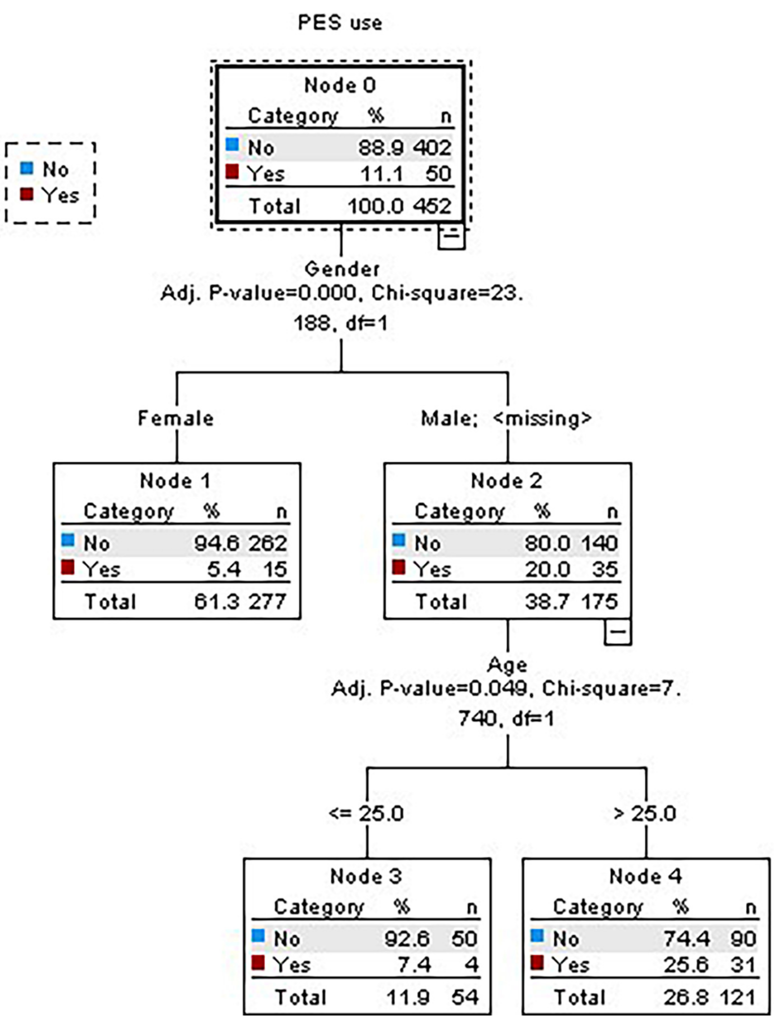

FIGURE 1
Decision tree for sociodemographic characteristics.

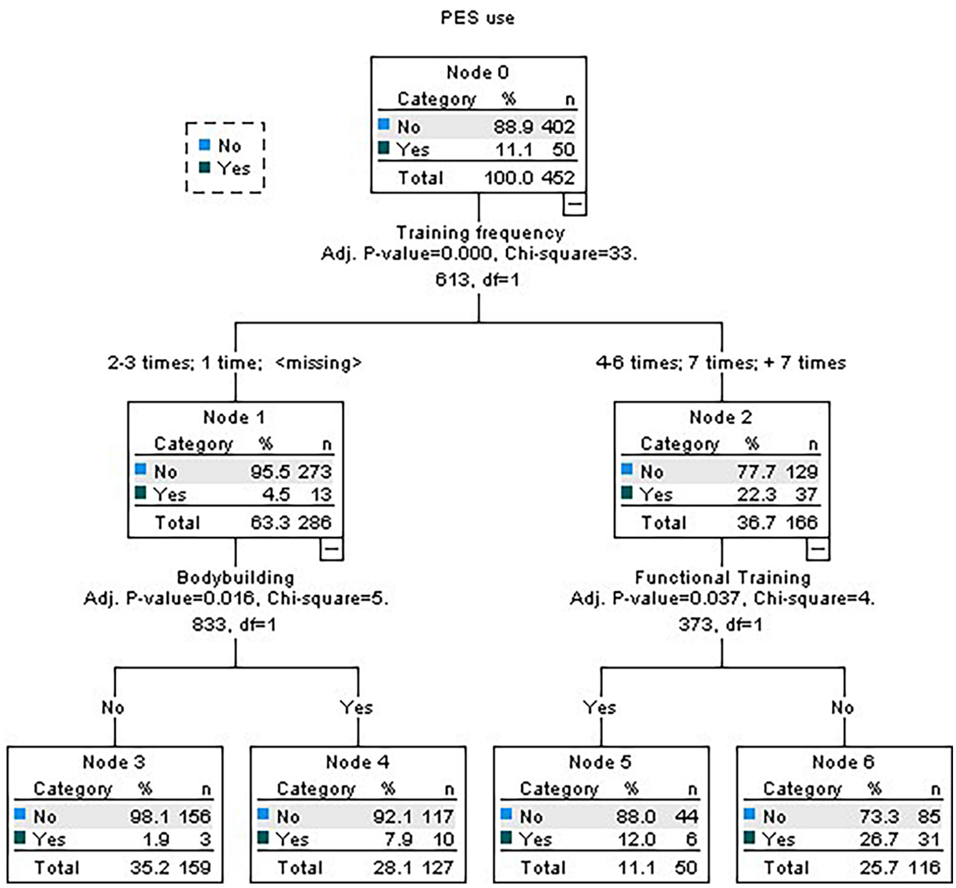

FIGURE 2
Decision tree for activities practiced, training frequency, and training time.

protective factors of PES use in fitness context related to non-user population, considering the components of TPB, although a considerable number of studies try to understand why athletes refrain from engaging in PES, on the broad sport context (Leone and Fetro, 2007; Bloodworth and McNamee, 2010; Zenic et al., 2013; Erickson et al., 2015). Therefore, the main purpose of this study was to identify the profile characteristics of the non-use of PES of gym- goers, following the same approach of Tavares et al. (2020a) used to study the determinants to consume PES in the same population. Moreover, the association of gender and type of sport activity with the self-reported behavior of PES was also studied.

More specifically, hypotheses state that the unfavorable evaluation of attitude toward substance consumption, the absence of a subjective norm that emphasizes consumption, and the unfavorable beliefs about the outcomes of PES consumption are associated with the intentions of PES non-use. In line with previous studies (e.g., Lucidi et al., 2004, 2008; Allahverdipour et al., 2012; Chan et al., 2015a), results of the multiple linear regression confirm these hypotheses suggesting that the variation of scores on these variables have a direct and positive relationship with the intention scores. It was also expected that favorable intentions toward PES use were negatively associated with self-reports of PES non-use behavior. In fact, in the current study, when beliefs, subjective norms, intention, and attitudes were considered, only intention was significantly associated to the PES non-use which is supported by the fact that among the non-consuming subjects 97% have a negative intention to use PES. Moreover, when all the components were included in the decision tree model, only intention proved to be significant. This is consistent with the TPB model and results from previous studies investigating PES use (e.g., Lucidi et al., 2004, 2008; Wiefferink et al., 2008) suggesting the need to promote behavior free of PES through educational interventions emphasizing the determinants of intentions of healthy behaviors. For example, taking into consideration the relationship between attitudes and subjective norms with intentions, a main target of educational programs should be the social context of individuals namely the instructors of clubs and exercise centers. Additionally, educational programs aiming at preventing gym-goers's use of PES should also convey information on the potentially dangerous impact of these substances on health so that negative intentions toward PES develop.

The final hypothesis is also confirmed. It stated that the female practitioners and those who practice non-strength-based activities are more likely to report non-use of PES. Results show the importance of gender as 94.5% of women do not consume PES versus 80% of men, which is in line with other studies (Serpa et al., 2003; Ntoumanis et al., 2014; Sagoe et al., 2015; Backhouse et al., 2016; Nicholls et al., 2017; Tavares et al., 2020a; Collomp et al., 2022). As to the type of activity, 98.1%

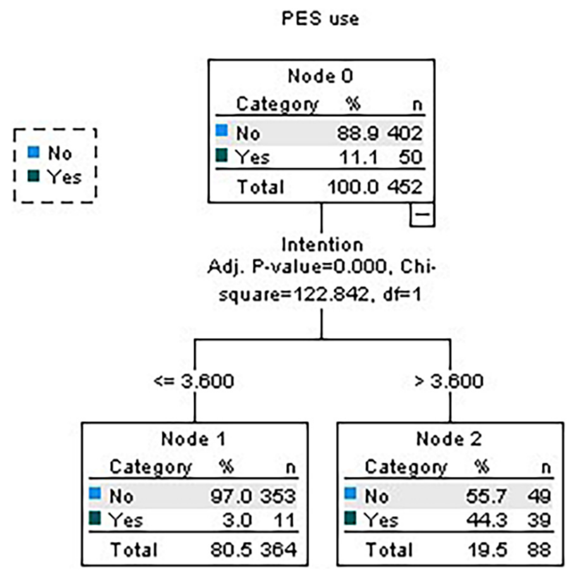

FIGURE 3
Decision tree for beliefs, subjective norms, attitudes, and intention.

of the non-consuming subjects do not practice bodybuilding. Additionally, results show that 95.5% of those who have a lower training frequency, and 88% of those who practice functional training, are not PES consumers. These results may be explained by the fact that activities such as cardio fitness, stretching or localized gymnastics are not so connected with results influenced by those substances versus strength-based activities (Wichstrøm, 2006; Tavares et al., 2020b; Mantri et al., 2023). On the other hand, female subjects in the current study are mostly involved in those types of exercising and they may have motivations related to general physical wellbeing instead of over-shaping their muscles with the help of PES. In what concerns the frequency of training per week, it may suggest that physical wellbeing and health goals may be the main purposes to be reached by the lower frequent practitioners. Moreover, in this group there is a significant association with not practicing bodybuilding activities that are very much connected to a certain type of extrinsic social motives facilitating the use of external enhancers (Macho et al., 2021). On the other hand, among the subjects that have a higher frequency per week, most of those who are involved in functional training are PES non-consumers, which suggests that their aim may be being in good physical shape by means of a natural physiological process.

It was also found that the male group under 25 years old emerges significantly as PES non-consumers when compared to older male subjects perhaps because in this period of life subjects feel comfortable with their physical capacities and do not feel the need to enhance them with the help of specific substances. Moreover, intrinsic motives may be stronger than extrinsic ones, which are more strongly related to the use of PES (Ip et al., 2015).

Several aspects were found that are associated to the behaviors of not using PES in the gym-goers population, which are related (i) to cognitive factors analyzed through the TPB framework, (ii) to the subjects' characteristics and their behavioral approach to the activities, and (iii) to the chosen type of activities. Regarding the cognitive factors, results suggest that intentions related to the PES non-use are strongly associated to this actual behavior. Moreover, individuals who have a negative intention to consume PES do not consume it. As to gender, age and time commitment, female, and younger male gym-users and those with lower frequency of gym activities show the higher percentage of non-use of PES. Regarding the activities, results suggest that functional training and not being involved in bodybuilding are associated to PES non-use.

4.1 Practical implications

The findings of the present research study have important implications for current research on the characteristics related to the decision not to use performance-enhancing substances among gym-goers. The analysis of the sample characteristics together with the type of practice gives important information concerning the subjects' non-use behaviors. Understanding the choices of this specific population concerning not to use PES, could support future intervention strategies to prevent this phenomenon in gymnasium context (Erickson et al., 2015). PES-prevention activities targeting older males and bodybuilding practitioners should form part of a comprehensive multi-systemic PES prevention approach, reinforcing the negative health impact of these substances and healthy alternatives (Horta, 2017). Indeed, medical support and regular health checkups should be promoted among this type of population. Future studies should take in account other psychological constructs such as self-control, resisting social pressure, moral conviction, self-esteem, perfectionist strivings and happiness, as they tend to be associated with PES refusal (Nicholls et al., 2017).

TABLE 1 Multiple linear regression model to identify predictors of intention.

Model[a]	Unstandardized coefficients		*t*	*p*	95% confidence interval for *B*		Collinearity statistics	
	B	SE			Lower bound	Upper bound	Tolerance	VIF
(Constant)	−1.000	0.139	−7.196	0.000	−1.273	−0.727		
Attitudes	0.259	0.035	7.438	0.000	0.191	0.328	0.839	1.192
Subjective norms	0.821	0.049	16.610	0.000	0.724	0.918	0.780	1.282
Beliefs	0.302	0.038	7.962	0.000	0.227	0.376	0.784	1.276

[a]Dependent variable: intention.

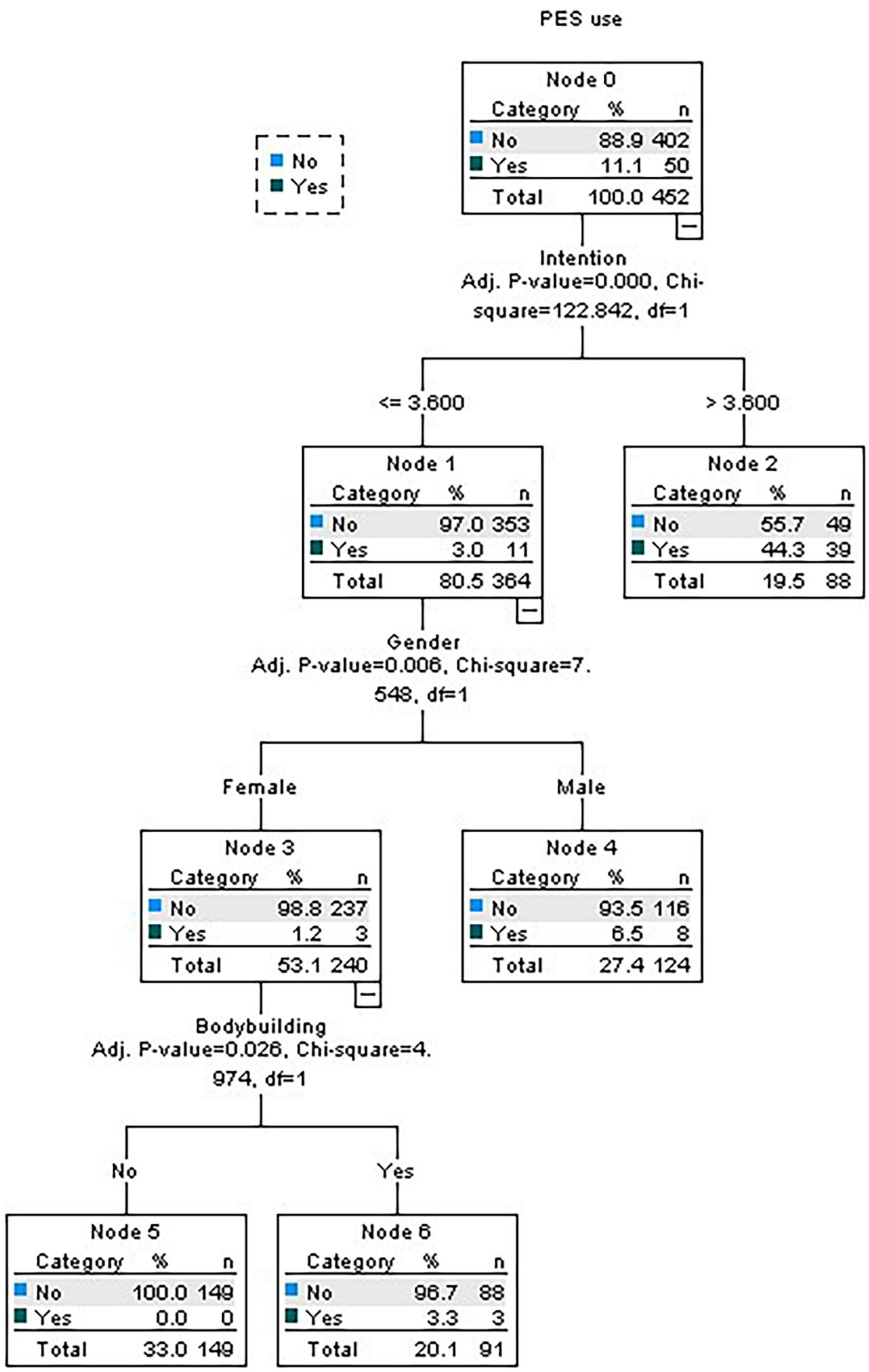

FIGURE 4
Decision tree for global profile.

4.2 Limitations and future work

Several limitations of this study should be addressed and suggestions for future research considered. First, this study is a cross-sectional survey, which means findings do not inform about the behavior of PES non-use, in those who showed unfavorable beliefs about the outcomes of PES consumption, that is, causal inferences based on the current findings should be avoided. Future studies will benefit from longitudinal designs to enable a precise observation of how unfavorable beliefs about the outcomes of PES consumption in fitness context, could be associated with the absence of PES use behavior, by gym-goers. Second, the non-probabilistic nature of sampling limits the result's generalization to the wider population of gym-goers. Thirdly, this study was based on self-reporting, which could lend itself to social desirability and response bias. Third, on top of methodological limitations, our study only examined relationships between psychological variables, socio-demographic variables and some types of practice, training frequency, and training time, which limits an understanding of the "whole picture," concerning the reasons for PES non-use. That is, we do not identify the protective factors that safeguard gym-goers from PES use. According to Chan et al. (2015b), PES use avoidance involve a broad range of behaviors and this behavior could "take place at anytime and anywhere"; hence, methods, such as implicit association tests, might measure this behavior in a more reliable and objective manner. Moreover, a qualitative approach, using data collection techniques like unstructured observation or open interviews, may yield significant insights into the belief systems underpinning gym-goers' motivation and intentions to not use PES, as it does not entirely define the variables and their values *a priori*, leading new information and knowledge (Lucidi et al., 2016). Finally, it is important to consider the cultural characteristics of the samples because individuals may hold, for example, different values and beliefs grounded on cultural influences or subject to diverse regulatory policies. Nevertheless, studies have utilized samples from a variety of countries (e.g., Iran, Allahverdipour et al., 2012; Netherlands, Wiefferink et al., 2008; Portugal, Tavares et al., 2020a), including Lazuras et al. (2017) cross-cultural study with samples from Cyprus, Greece, UK, Germany, and Italy. More research is needed to explore how cultural factors further influence gym-goers choices concerning PES use or non-use.

5 Conclusion

In conclusion, this study shed light on fundamental aspects related to the decision not to use performance-enhancing substances among gym-goers. Findings showed that cognitive factors, particularly negative intentions, play a crucial role in the conscious choice not to use these substances. Furthermore, distinct demographic differences emerged, highlighting a gender disparity, with 94.5% of women and 80% of men opting not to use these substances. Age was also an important characteristic with younger men, especially those under 25, demonstrating significant resistance to PES use, possibly driven by intrinsic motivations and satisfaction with their physical abilities. Regarding activities, those engaged in functional training and not practicing bodybuilding showed a clear preference for not resorting to these substances. Indeed, these younger men may search mostly for the pleasure of the chosen physical practice and not just for its outcome. Moreover, in the younger ages physiological and morphological results are faster and more evident which may reduce the wish to enhance them with PES. Thus, this work provides valuable insights, showing the way for more refined interventions aimed at promoting a culture of health and substance-free fitness practices.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the Ethical Committee of the University of Lisbon, Faculty of Human Kinetics. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

AT: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. EC: Data curation, Formal analysis, Methodology, Writing – review & editing. PT: Supervision, Writing – original draft, Writing – review & editing. LC: Supervision, Writing – original draft, Writing – review & editing. SS: Conceptualization, Data curation, Methodology, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

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Neuropsychological analysis of anxiety and executive control of motor patterns in athletes and non-athletes

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Introduction: Even simple tapping tasks require cognitive processes. Some variants of the Finger Tapping Test (FTT) may reveal cognitive aspects associated with frontal processing, including executive functions such as inhibition, or emotional aspects such as anxiety. A context of particular interest for the application of cognitive-motor-anxiety interactions is sports. Although athletes generally exhibit better anxiety levels, they may experience heightened anxiety before important competitions. The problem lies in determining whether the application of anxiety control techniques can be useful in pre-competition situations, given the lack of quick and easy methods to detect if an athlete is experiencing anxiety at a particular moment.

Methods: This exploratory study evaluated anxiety using online versions of questionnaires (ISRA, the Competitive State Anxiety Inventory-2, and STAI) and applied a variant of the FTT to 204 participants, both athletes and non-athletes. The scores were compared and correlated.

Results: Athletes exhibited lower general anxiety and greater cognitive resistance to interference (better cognitive inhibition). Non-athletes displayed a particular parameter in the FTT variant that differed from the one obtained by athletes and exhibited higher anxiety levels. In the athletes' group only, anxiety was correlated with a specific parameter of the FTT task.

Discussion: Our conclusion is that this parameter holds potential relevance in elite sports performance to detect if an athlete is experiencing anxiety. It could be of particular interest in psychological interventions in sports. Further investigation is warranted to fully explore this potential.

KEYWORDS

Finger Tapping Test, anxiety, executive functions, cognitive inhibition, sport psychology

1 Introduction

The Finger Tapping Test (FTT) was developed as part of the Halstead-Reitan Neuropsychological Test Battery (HRNB) for neuropsychological evaluation (Halstead, 1947; for reviews, Allen, 2011; Schatz, 2011). The original test mainly measures motor speed as the average number of tapping events that a patient emits in 5 trials of 10 s, aimed at evaluating brain injuries (Russell et al., 1970; Allen, 2011). This original version of the task involves a high level of motor requirements, as evidenced in functional Magnetic Resonance Imaging (fMRI) studies, which showed that participants performing the FTT exhibited Blood Oxygenation Level Dependent (BOLD) activity in motor-related brain areas, such as the motor cortex, premotor cortex, supplementary motor cortex, cerebellum, and cortico-striatal-thalamic loop circuits (Turesky et al., 2018). These areas are related to movement speed, coordination, and rhythm maintenance.

However, and very interestingly, motor areas are not the only ones active. The same authors reported brain activity (meaning, significant BOLD signal) in non-motor areas, such as the inferior and middle occipital gyrus, lingual gyrus, anterior cerebellum, thalamus, supramarginal gyrus, cuneus, and left insular cortex (Turesky et al., 2018). This implies that even highly motor-related activities, such as tapping tasks, require non-motor cognitive processes to be performed (Holtzer et al., 2006; Bielak et al., 2010). Further evidence exists regarding the cognitive involvement in this task. For instance: (a) frontal lesions due to surgery, without damage in motor cortices, reduce tapping task performance (Leonard et al., 1988); (b) FTT is sensitive to some cognitive aspects, to mood states related to dementia, to certain neurodegenerative disorders (Wefel et al., 1999; Arias et al., 2012), acquired brain injury (Geldmacher and Hills, 1997), neuropsychiatric diseases (Heaton et al., 1978; Flashman et al., 1996), and to certain pharmacological substances with cognitive/psychiatric effects (Shaw et al., 1987; Swift and Tiplady, 1988; Roth and Bättig, 1991; Heishman et al., 1994); and (c) performance in FTT predicts cognitive decline (Camicioli et al., 1998).

Despite its significance, the cognitive aspects underlying the Finger Tapping Test (FTT) are not as thoroughly understood as its motor counterparts. Furthermore, its interaction with other systems, such as emotional or motivational processes including anxiety, remains less explored. While FTT use is primarily confined to motor assessment, deficient motor performance may result from impaired cognitive processing, the effects of which are manifested in the motor system. For example, white matter lesions associated with decreased speed processing may adversely affect motor skills, even though their etiology is not exclusively motor-related (Hinton et al., 2018; Andreasen et al., 2019; Rasooli et al., 2023). Hence, it is imperative to comprehend the cognitive processes involved in this task comprehensively, including their relationships with other domains. The development of new FTT variants that facilitate such investigations holds promise for advancing basic research and its application in specific contexts, such as sport psychology.

In this context, certain FTT variants modify the speed of different tapping blocks during the test to assess central versus peripheral fatigue (Arias et al., 2012; Aydin et al., 2016), or alternate sequences of normal-quick-normal-slow rhythms (González, 2001; Mendo et al., 2011). These variants have the potential to reveal cognitive challenges associated with inhibition and interactions with other neuropsychological systems related to executive functions or the proper adjustment of motor patterns. The rationale behind this lies in the fact that altering motor rhythms necessitates inhibiting previous motor patterns, cognitive flexibility to alternate between different speeds in a correct order, and executive attentional oversight of the task. In essence, changing rhythms demands executive functions associated with prefrontal brain areas (Fuster, 2001; Tirapu-Ustárroz et al., 2008a,b; Funahashi and Andreau, 2013), their projections onto limbic regions or the insular cortex (Selemon and Goldman-Rakic, 1988), and basal nuclei, primarily the caudoputamen, which have direct effects on the corticostriatal-thalamic loop (Graybiel et al., 1994; Beste et al., 2018; Florio et al., 2018), directly implicated in the correct execution of FTT (Turesky et al., 2018).

On the other hand, neurobiological circuits associated with anxiety are among the neuropsychological systems that may interact with cognitive aspects underlying FTT when changes in rhythms are required (for reviews on the neuroanatomy of anxiety, see Etkin, 2010; Schmidt et al., 2018; Goossen et al., 2019). Briefly, although amygdala is the main anxiogenic nucleus within the limbic system (Etkin and Wager, 2007), other brain regions, such as the insula and cingulate cortices, also become co-activated during uncertain situations or states of anticipatory anxiety (Sarinopoulos et al., 2010). Simultaneously, dorsolateral and orbitofrontal prefrontal cortices show decreased activity, particularly in the presence of emotional conflict (Comte et al., 2015). Impaired prefrontal attentional control has been directly linked to anxiety in some studies (Bishop, 2009). All these regions have been associated with executive functions and/or are implicated in their integration with motor patterns (Selemon and Goldman-Rakic, 1988; Graybiel et al., 1994; Fuster, 2001; Funahashi and Andreau, 2013; Beste et al., 2018) suggesting that they could be nodes of particular interest for understanding the interactions among cognitive, motor, and emotional (anxiety) domains. If so, they could be elucidated by varying classic FTT conditions, such as altering rhythmic patterns (as done previously in González, 2001; Mendo et al., 2011).

If validated, the application of this FTT variant could be particularly relevant in the context of sport psychology. Generally, athletes exhibit lower levels of anxiety overall (excluding pre-competitive anxiety states, as discussed below) compared to non-athletes (Tilindiene et al., 2014). This may be attributed to higher stress exposure during sport practice or their training to develop coping strategies for such situations (Rice et al., 2019). Regardless, this adaptation to stressful circumstances enhances their control over anxiety, mitigating the effects of environmental demands even in other aspects of life (Correia and Rosado, 2019).

However, despite the general reduction in anxiety levels due to sport practice, most athletes experience a heightened state of anxiety before important competitions, known as pre-competitive anxiety. This state is driven by uncertainty, anticipatory anxiety, and emotional conflict prior to competitions. It is observed in athletes but not in control groups (those who do not engage in competitive sports and thus lack pre-competitive exposure), complicating comparative studies. This anxiety state is likely associated with increased activity in the insular and cingulate cortices (Sarinopoulos et al., 2010) and hypoactivity in prefrontal regions, including the dorsolateral and orbitofrontal cortices (Bishop, 2009; Comte et al., 2015). These brain regions are also crucial for various aspects of executive functions required for different FTT variants.

Given their shared neural substrates, FTT variant tasks that require executive functions (such as resistance to interference) could serve as indirect assessments of anxiety. These tasks are valuable, quick, easy to interpret, and inexpensive. In elite sports, such assessments could potentially make the difference between winning and losing by addressing performance errors preemptively through the application of anxiety-control techniques, if necessary, before competition.

This research aims to delineate patterns of anxiety and motor pattern alternation (requiring executive functions such as cognitive inhibition and resistance to interference) in athletic populations, with the expectation of identifying statistically distinct ranges compared to non-athletic populations. Additionally, it endeavors to establish statistically significant relationships between performance on the Finger Tapping Test and self-reported anxiety levels using various questionnaires.

2 Materials and methods

2.1 Participants

A total of 204 young adults participated in this research (55.69% female; 44.31% male), with ages ranging from 21 to 28 years ($M = 22.14$; SD = 1.57). G*Power software (v.3.1.9.7; Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) was used to calculate the sample size. For the tests used in the study, with a type I and II error probability of 5%, a confidence level of 95% and statistical power of 0.95, the minimum required sample size was 168. Participants were from Andalusia, Spain. 46.08% of the sample practiced sports (Athletes group), between one to five days a week, while 53.92% do not have physical activity (No-Athletes group). There were no statistically significant age differences between groups (Athletes: $M = 21.91$; SD = 1.37; No-Athletes: $M = 22.33$; SD = 1.70) ($Z = -1.59$, $p > 0.05$). The athletes group was heterogeneous, including people who compete at local, regional and national levels, in different sports, including individual, adversarial and team sports (e.g., athletics, judo, tennis, basketball, football, among others). All athletes had eight or more years of sports experience. Inclusion criteria were to be aged between 20 and 30 years and completing all items on the questionaries. Exclusion criteria included being outside the specified age range, incomplete questionaries responses, and having any physical or psychological condition that could compromise the study. The range of 20–30 years was selected because frontal lobe maturation (and thus execute functions) is complete at that stage (Gogtay et al., 2004).

2.2 Measurements and instruments

(a) Inventory of Anxiety Situations and Responses (ISRA, Miguel-Tobal & Cano-Vindel, 1994). The ISRA has an S-R (situations-responses) format, made up of 22 situations and 24 anxiety responses. The 22 situations have been grouped into four areas or specific anxiety traits: evaluation situations, interpersonal situations, phobic situations and everyday life situations. The 24 responses are grouped into three subscales that evaluate the three response systems: cognitive, physiological and motor. The internal consistency values (Cronbach's Alpha) for this research were as follows: cognitive = 0.81, physiological = 0.78 and motor = 0.83.

(b) Competitive State Anxiety Inventory–2. This questionnaire was proposed by Martens et al. (1990) and assesses competitive anxiety and self-confidence, using 27 items and three factors: cognitive anxiety, somatic anxiety and self-confidence. In this investigation, the Spanish version developed by Capdevila (1997) was used. The results were evaluated using a Likert scale from one (almost never) to five (almost always). The internal consistency values (Cronbach's Alpha) for this research were as follows: cognitive anxiety = 0.73, somatic anxiety = 0.85 and self-confidence = 0.90. This questionnaire was done only by Athletes group.

(c) State Trait Anxiety Inventory (STAI, Spielberger et al., 1970). This questionnaire allows evaluating state and trait anxiety. It consists of 40 items and two factors: state and trait anxiety. Scores in each can range from 0 to 60 points. Each item is answered based on 4 levels 0, 1, 2, and 3. The internal consistency values (Cronbach's Alpha) for this research were as follows: state anxiety = 0.76 and trait anxiety = 0.74.

(d) Finger Tapping Test v. 1.0.39[1] (Mendo et al., 2011). It consists of an online variant of the classic task originally developed by Halstead (1947), applied on MenPas platform. While the original task primarily aimed to evaluate motor control, FTT-based variants could modify different parameters related to associated theoretical aspects. For example, alterations in the speed of tapping blocks may reveal central versus peripheral fatigue (Arias et al., 2012; Aydin et al., 2016). In this variant, alternate sequences of normal-quick-normal-slow rhythms were modified based on previous findings (González, 2001; Mendo et al., 2011). Briefly, the task requires clicking on a button that appears on the screen for 10 s with 4 different rhythms, in a specific order: first, normal speed (labelled as A); second, high speed (quick); third, normal speed again (labelled as B); fourth, slow speed. Frequency of clicking and latency between pulses are recorded for each velocity, although only frequency was taken into account for this study. Despite normal speed being repeated in the first and third positions, there is an interference speed (quick) between them. Thus, by subtracting A – B execution parameters, we could reveal this putative interference. The closer to 0 the A - B value is, the less the interference of the quick phase affects the "normal" speed B. Resistance to interference has been linked to executive functions, such as cognitive inhibition and flexibility (Friedman and Miyake, 2004; Diamond, 2013); and the failure to inhibit distractors has been associated with anxiety (Bishop, 2009).

2.3 Procedure

Initial contact with participants and data Research Topic for this exploratory study were conducted using the MenPas psychosocial evaluation platform (see Footnote 1) between January and June 2023. Voluntary cooperation was requested for participation in the research, and informed consent was obtained. The sample selection method was non-probabilistic, using convenience and snowball sampling techniques. Participants had access to the researchers' contact details and could request

1 www.menpas.com

information about the study. They were informed that they needed to complete various questionnaires and perform the Finger Tapping Test variant task, which took approximately 45 min to complete. After explaining the purpose of the study and ensuring anonymity and confidentiality in the handling of the data, the evaluation was conducted. Throughout the study, ethical principles outlined in the Helsinki Declaration (World Medical Association, 2013) were adhered to. The study received approval from the ethics committee of the University of Malaga (Spain). Data were stored securely on the platform and downloaded using a password-protected Excel sheet. Subsequently, the data were exported to the SPSS statistical package for analysis.

2.4 Data analysis

Descriptive and inferential analyses were performed. The normality of the data distributions was also tested by means of the Kolmogorov–Smirnov test. In addition, the reliability of the different scales used was analyzed by evaluating internal consistency (Cronbach's alpha). To analyze the correlations between the measures considered, the Spearman coefficient was used, considering the parameters described by Evans (1996) (±0.01 to ±0.19 = very weak correlation; ±0.20 to ±0.39 = weak correlation; ±0.40 to ±0.59 = moderate correlation; ±0.60 to ±0.79 = high correlation). The Mann–Whitney was used to determine possible differences between groups, while Wilcoxon test was used to compare within group. They were applied given that Kolmorogov-Smirnov tests indicated that data did not fit with normal distributions. Besides, Cohen's d was used to estimate the effect size of the differences [≈0.20: small, ≈0.50: medium, and ≈0.80: large (Hojat and Xu, 2004)]. The level of significance was set at $\alpha = 0.05$. Likewise, the effect size was calculated using Cohen's d. The SPSS statistical package was used for the statistical treatment of the data (SPSS Inc. v.25.0, Chicago, IL, United States).

3 Results

In Table 1, the means, standard deviations, skewness, and kurtosis values for the study variables are presented. Overall, the skewness and kurtosis values fall within acceptable ranges. However, Kolmogorov–Smirnov tests indicate significant results ($p < 0.05$) for most dimensions, both for the total sample and depending on the sport practiced. This suggests a deviation from normal distribution for the dataset, so non-parametric statistic was used when appropriated.

Table 2 presents differences based on the type of sports activity undertaken. It is evident that, across all comparisons, the group engaged in sports activities (Athletes) exhibits lower scores on anxiety scales. Specifically, individuals participating in sports activities demonstrate lower levels of state and trait anxiety, as well as reduced cognitive, physiological, and motor anxiety responses ($p < 0.001$). However, while a distinct pattern is observed between the groups of athletes and non-athletes in the Finger Tapping Test, with athletes displaying a higher tapping frequency and shorter execution time, these differences are not statistically significant in most cases ($p > 0.05$). However, statistically significant differences were found between the tapping frequencies in normal rhythm A minus normal rhythm B ($p < 0.05$).

Additionally, the Wilcoxon test (not included in the table) indicated that there were no statistically significant differences between the pulsation frequency of the normal rhythm phase A and B in the athlete sample [$Z = -0.75$; $p > 0.05$; Cohen's $d = -0.02$, 95% CI (−0.43, 0.37)], but there were in the total sample [$Z = -3.68$; $p < 0.001$; Cohen's $d = 0.08$, 95% CI (−0.20, 0.35)], and non-athletes [$Z = -4.34$; $p < 0.001$; Cohen's $d = 0.23$, 95% CI (−0.15, 0.60)].

Table 3 displays the correlation analyses conducted. For the total sample, statistically significant inverse correlations were observed between taps frequency in Normal Rhythm A and the cognitive and motor scales of the ISRA, as well as between Normal Rhythm A and B and trait anxiety. Among athletes, statistically significant inverse correlations were found between the frequency of taps in Normal

TABLE 1 Descriptive data.

	Total				Athletes				Non-Athletes			
	M	SD	S	K	M	SD	S	K	M	SD	S	K
ISRA - Cognitive	132.89	67.07	0.20	−0.71	114.46	60.93	0.32	−0.61	148.65	68.32	0.03	−0.75
ISRA - Physiological	82.90	60.32	0.99	0.37	67.35	52.05	1.80	3.97	96.20	63.86	0.52	−0.64
ISRA - Motor	84.33	66.24	1.02	0.29	68.41	66.47	1.60	1.90	97.94	63.23	0.70	−0.22
CSAI2 - Cognitive anxiety	–	–	–	–	30.55	3.76	0.36	0.48	–	–	–	–
CSAI2 - Somatic anxiety	–	–	–	–	26.00	8.51	−0.14	−0.75	–	–	–	–
CSAI2 – Self-confidence	–	–	-	-	33.51	7.06	−0.22	−0.24	–	–	–	–
STAI – State anxiety	17.36	10.21	0.78	0.20	13.54	9.23	1.10	1.46	20.62	9.90	0.74	−0.22
STAI – Trait Anxiety	20.17	10.11	0.03	−0.66	17.12	10.87	0.25	−0.89	22.78	8.63	0.23	−0.56
FTT - Normal rhythm A	14.11	7.98	1.94	4.13	15.81	9.97	1.51	1.64	12.66	5.40	1.71	4.85
FTT - Fast rhythm	56.63	7.10	−0.55	4.09	57.50	6.24	−1.36	6.09	55.88	7.71	−0.09	3.53
FTT - Normal rhythm B	14.69	7.24	1.54	3.76	15.54	8.41	1.67	3.58	13.95	6.01	0.81	0.55
FTT - Slow rhythm	7.84	3.63	1.46	3.31	8.13	4.07	1.15	1.85	7.59	3.20	1.83	5.74
FTT - Normal rhythm A-B	−0.57	3.85	1.10	5.46	0.27	4.57	1.53	3.52	−1.29	2.93	−1.30	3.47

Descriptive statistics for the total sample and based on sports practice in measures of ISRA, CSAI-2, STAI, and Finger Tapping Test. M, Mean; SD, Standard Deviation; S, Skewness; K, Kurtosis.

TABLE 2 Comparisons between athletes and non-athletes.

	U Mann–Whitney	Z	p	Cohen 'd	CI (95%)
ISRA - Cognitive	3656.00	−3.60	< 0.001	0.55	[0.27, 0.83]
ISRA - Physiological	3791.00	−3.28	< 0.001	0.49	[0.21, 0.77]
ISRA - Motor	3292.00	−4.47	< 0.001	0.46	[0.18, 0.74]
CSAI2 - Cognitive anxiety	–	–	–	–	–
CSAI2 - Somatic anxiety	–	–	–	–	–
CSAI2 – Self-confidence	–	–	–	–	–
STAI – State anxiety	2933.50	−5.33	< 0.001	0.74	[0.45, 1.02]
STAI – Trait anxiety	3570.00	−3.81	< 0.001	0.58	[0.30, 0.86]
FTT - Normal rhythm A	4528.50	−1.53	0.126	–	–
FTT - Fast rhythm	4461.00	−1.69	0.091	–	–
FTT - Normal rhythm B	4875.50	−0.70	0.483	–	–
FTT - Slow rhythm	4856.00	−0.75	0.452	–	–
FTT - Normal rhythm A-B	4333.00	−2.01	< 0.05	0.41	[0.14, 0.69]

Group comparisons for the ISRA, CSAI-2, STAI, and Finger Tapping Test measures.

TABLE 3 Correlations matrix between FTT, anxiety measures as function of the group.

		FTT - Normal rhythm A	FTT - Fast rhythm	FTT - Normal rhythm B	FTT - Slow rhythm	FTT - Normal rhythm A-B
Total	ISRA - Cognitive	−0.14*	0.04	−0.13	−0.08	−0.06
	ISRA - Physiological	−0.04	−0.04	−0.01	−0.02	−0.05
	ISRA - Motor	−0.16*	−0.11	−0.10	0.01	−0.04
	CSAI2 - Cognitive anxiety	–	–	–	–	–
	CSAI2 - Somatic anxiety	–	–	–	–	–
	CSAI2 – Self-confidence	–	-	–	–	–
	STAI – State anxiety	−0.07	−0.08	−0.09	−0.01	0.10
	STAI – Trait anxiety	−0.17*	0.02	−0.18*	−0.04	−0.02
Athletes	ISRA - Cognitive	−0.21*	−0.01	−0.22*	−0.08	−0.07
	ISRA - Physiological	−0.05	0.04	0.01	0.08	−0.10
	ISRA - Motor	−0.14	0.02	−0.09	0.02	−0.09
	CSAI2 - Cognitive anxiety	0.01	0.03	0.05	0.01	0.04
	CSAI2 - Somatic anxiety	−0.07	−0.05	−0.12	−0.05	0.22*
	CSAI2 – Self-confidence	0.25*	0.01	0.23*	0.08	−0.06
	STAI – State anxiety	−0.04	0.02	−0.14	0.08	0.25*
	STAI – Trait anxiety	−0.20*	−0.10	−0.21*	−0.02	−0.05
Non-Athletes	ISRA - cognitive	0.01	0.07	−0.01	0.01	0.05
	ISRA - Physiological	0.01	−0.08	0.01	−0.09	0.03
	ISRA - Motor	−0.09	0.02	−0.09	−0.04	−0.02
	CSAI2 - Cognitive anxiety	–	–	–	–	–
	CSAI2 - Somatic anxiety	–	–	–	–	–
	CSAI2 – Self-confidence	–	–	–	–	–
	STAI – State anxiety	−0.03	−0.07	−0.04	−0.06	−0.04
	STAI – Trait anxiety	−0.10	−0.06	−0.14	−0.07	0.03

Spearman correlation analysis between ISRA, CSAI-2, STAI measures and the Finger Tapping Test (total sample by sports participation).

Rhythm A and B with the cognitive scale of the ISRA, self-confidence, and trait anxiety. Furthermore, differences between Normal Rhythm A and B correlated significantly and positively with somatic anxiety and state anxiety. Conversely, the non-athlete group showed no statistically significant relationships with the ISRA and STAI factors.

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4 Discussion

The aim of this research was to observe differences in patterns of anxiety and executive function capacity to alternate between different rhythms of motor patterns among athletic and non-athletic populations. Additionally, it sought to identify statistically significant relationships between performance on the Finger Tapping Test (FTT) and levels of anxiety assessed. Initially, statistically significant differences were observed between athletes and non-athletes in cognitive, physiological, and motor anxiety responses measured with the ISRA, as well as in state and trait anxiety assessed with the STAI. Consequently, the non-athletic sample exhibited higher levels of anxiety across these measures. Regarding participants' performance in the FTT task, there were no statistical differences between groups in any rhythm (normal A, quick, normal B, or slow). Importantly, Wilcoxon analysis revealed that when subtracted A – B, the Athlete group tended to pulse an equal number of clicks in B as in A, indicating no interference of the quick pattern on B. However, the No-Athletes group expressed more pulses in B than in A, which may reflect less cognitive inhibition to suppress the intermediate quick motor pattern. Thus, the only differences in FTT parameters between groups are evident in pulsation frequencies in Normal Rhythms A minus B, with a more stable execution observed in athletes. Furthermore, no statistically significant relationships were found between FTT performance and anxiety measures in the non-athletic sample, while some significant relationships were noted between FTT execution rhythms and certain anxiety measures in the athletic sample (Table 3).

The results suggest that athletes generally experience lower levels of anxiety compared to non-athletes, consistent with findings from previous studies (Stubbs et al., 2018; Reigal et al., 2021), while the no athletic group exhibited higher scores in terms of both anxiety state and trait (Tilindiene et al., 2014). This is in line with research indicating that physical exercise and sports participation can mitigate anxiety symptoms, enhance stress-coping abilities, and provide individuals with resources and strategies to better navigate environmental pressures (Tilindiene et al., 2014; Dale et al., 2019). Engaging in physical activity serves as a distraction, facilitating relaxation processes and reducing the impact of daily stress and anxiety (Kandola and Stubbs, 2020). Furthermore, exercise promotes the synthesis of endorphins and serotonin, enhancing emotional regulation and mood (Alizadeh Pahlavani, 2024). Furthermore, sports practice enhances the functioning of neural circuits, including those situated in prefrontal areas, which play a key role in inhibitory control (Diamond, 2013; Guiney and Machado, 2013). These circuits are directly associated with emotional regulation through connections with the limbic system and other regions mentioned in the introduction, thereby contributing to improved stress and anxiety management (Gunther et al., 2022; Shanok et al., 2022).

Taking together, the data suggest that athletes not only exhibit lower overall anxiety levels but also display more stable A-B punctuations in normal patterns, with minimal interference from the quick pattern (tending towards zero). Conversely, non-athletes tend to demonstrate more interference from the quick pattern (as their tapping in normal rhythm B is higher than in normal rhythm A), and exhibit higher anxiety scores. The correlation matrix reveals weak correlations between FTT and anxiety scores, primarily observed in athletes. It may be attributed to the higher absolute FTT scores in athletes before subtracting A - B. Additionally, correlations are only evident in athletes, not in non-athletes, possibly due to the highly heterogeneous nature of the athlete sample, reflected in the higher standard deviation of FTT scores in this group.

Importantly, this exploratory study provides initial (to our knowledge) evidence suggesting the potential use of the FTT variant employed in the study as a tool to elucidate certain executive functions related to anxiety in athletes vs. non athletes population. However, further research is warranted to address the limitations of the current study (see below). While FTT task, or its variants, have been widely utilized in various domain such as dementias, acquired brain injury (Leonard et al., 1988; Arias et al., 2012), basic neuroscientific research (Bielak et al., 2010; Turesky et al., 2018), sport psychology (González, 2001; Mendo et al., 2011), and others (see introduction), it was done separately. The findings from this exploratory investigation suggest a convergence of disciplines, indicating the potential for future studies to explore novel applications of the FTT task. These areas of interest could include its application in sports, the psychological processes underlying anxiety, or its neurobiological basis.

The underlying rationale is that engagement in sports enhances frontal brain functioning, particularly inhibitory control (Diamond, 2013; Guiney and Machado, 2013), which is functionally linked with various psychological and neurobiological processes, including anxiety (Bishop, 2009). Having a quick, easy-to-use, and inexpensive tool such as this FTT variant could greatly aid in detecting these interactions. While the data presented here are preliminary, sharing them could be valuable given their potential implications. Future research could further investigate which aspects of sports, or which sports, potentiate these interactions (e.g., is it the physical activity itself or the social aspects of team sports?); determine the magnitude of A-B deviation necessary to indicate sensitivity to this effect, and explore other related research questions.

This research presents several limitations. Firstly, the athlete sample is highly heterogeneous, with participants practicing sports between one and 5 days a week, spanning a broad range of levels of engagement. A more refined categorization based on frequency of practice and level of competition would provide clearer insights into the relationship between sports participation and anxiety. Secondly, the study did not control for the level of sports practice, resulting in a sample that included athletes from various competitive levels, ranging from local to national competitions. This lack of control may introduce bias into the data analysis. However, due to the sample size limitations, further subgroup analyses were not feasible, and thus, the conclusions should be considered exploratory and serve as a starting point for more comprehensive investigations in the future. Thirdly, the Finger Tapping Test was administered only once, potentially introducing variability due to factors such as motivation and concentration. To mitigate this, future studies could incorporate multiple trials of the test to obtain more reliable measurements and minimize biases arising from comprehension difficulties, familiarization with the task, or attentional fluctuations during performance. Additionally, it would be valuable to stratify participants based on age and gender and conduct multilevel analyses to assess the potential influence of these sociodemographic variables on the study outcomes.

This research holds significant applied value. The FTT variant emerges as a valuable tool due to its simplicity, efficiency, and affordability in uncovering cognitive functions necessary for alternating between speed pattern, and its overlapping with other cognitive and emotional functions. It is particularly relevant in the context of sports practice among athletes and non-athletes alike. Notably, the parameter of A – B subtraction in normal rhythm execution within the FTT demonstrates considerable utility, highlighting distinctions between athletic and non-athletic populations. Among athletes, this parameter correlates with higher levels of somatic and state anxiety, indicating a potential link between inhibitory control and anxiety management. Also, in athletes tend to be 0, while non-athletes tend to be negative. While further analysis is warranted, preliminary findings suggest, as main conclusion of this work, that athletes tend to exhibit less interference from rapid patterns on normal speed execution in the FTT variant, indicative of enhanced inhibitory control and lower anxiety levels. It is evidenced specifically in the A-B scores, which is something explicit to allow sport psychologist interventions targeting precompetitive anxiety, wherein deviations from a trend towards 0 in A – B scores could signal the need for anxiety management techniques. Nevertheless, these conclusions remain tentative, underscoring the necessity for additional research to corroborate and expand upon these initial observations.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Ethical committee of the University of Malaga. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

JC: Data curation, Formal analysis, Writing – original draft, Writing – review & editing. RR: Data curation, Formal analysis, Writing – original draft, Writing – review & editing. VM-S: Conceptualization, Supervision, Writing – review & editing. JP-B: Writing – review & editing. MA: Conceptualization, Supervision, Writing – review & editing. AH-M: Conceptualization, Supervision, Writing – review & editing.

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Commit to your putting stroke: exploring the impact of quiet eye duration and neural activity on golf putting performance

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Introduction: There is a growing interest in characterizing the cognitive-motor processes that underlie superior performance in highly skilled athletes. The aim of this study was to explore neural markers of putting performance in highly skilled golfers by recording mobile EEG (electroencephalogram) during the pre-shot period.

Methods: Twenty-eight right-handed participants (20 males) with a mean age of 24.2 years (± 6.4) and an average handicap of +1.7 (± 6.4) completed a testing session. Following the warm-up, participants completed 140 putts from a distance of 8ft (2.4m), with putts taken from 5 different positions. While putting, participants wore an eye tracker and a gel-based EEG system with 32 electrodes. Time and frequency domain features of the EEG signals were extracted to characterize Movement-Related Cortical Potentials (MRCP) and rhythmic modulations of neural activity in theta, alpha, sensorimotor and beta frequency bands associated with putting performance.

Results: Eye-tracking data demonstrate that mean Quiet Eye durations are not a reliable marker of expertise as the same duration was found for both successful and unsuccessful putts. Following rigorous data processing data from 12 participants (8 males, mean age 21.6 years ± 5.4, average handicap +1.5 ± 4.4) were included in the EEG analysis. MRCP analysis revealed performance-based differences, with unsuccessful putts having a greater negative amplitude in comparison to successful putts. Time frequency analysis of the EEG data revealed that successful putts exhibit distinct neural activity profiles compared to unsuccessful ones. For successful putts, greater suppression of beta was present in the central region prior to the putt. By contrast, increased frontal theta power was present for unsuccessful putts immediately before the putt (consistent with hesitation and the need for motor plan adjustments prior to execution).

Discussion: We propose that neural activity may provide plausible insights into the mechanisms behind why identical QE durations can lead to both success and failure. From an applied perspective, this study highlights the merits of a multi-measure approach to gain further insights into performance differences within highly skilled golfers. We discuss considerations for future research and solutions to address the challenges related to the complexities of collecting clean EEG signals within naturalistic sporting contexts.

KEYWORDS
golf putting, expertise, quiet eye, EEG, performance

1 Introduction

Putting constitutes a fundamental aspect of the sport of golf, wherein a putter is required to strike the ball into the hole when it lies on (or just short of) the green. From a practical standpoint, proficient putting is paramount, due to its significant impact on overall performance and subsequent success (Baugher et al., 2016). From a scientific perspective, the nature of golf putting offers an ideal platform for investigating the cognitive processes underlying skilled performance. The process of putting involves a routine that makes it amenable to study; preceding the initiation of the putting action and the commencement of the backswing, there exists a phase of motor preparation during which the golfer assumes a static posture with the putter head positioned just behind the ball (referred to as the "address" in golf terminology). Investigating the processing that occurs during this pre-shot period, leading up to the putt, should furnish insights into the underlying cognitive and neural mechanisms governing action preparation (Gallicchio et al., 2017).

Over recent years, researchers investigating the putting motor preparation period have predominantly focused on investigating eye movements stillness, or Quiet Eye (QE), a metric derived from eye-tracking recordings. QE is defined as the final fixation or tracking gaze on a specific location that has an onset prior to the start of a final, critical movement (Vickers, 2007). When applied to golf putting, research has recommended maintaining a steady vision on the back of the ball (Vickers, 1996). Optimal QE duration is thought to involve the player keeping their eyes fixated on the ball for 2000–3000 ms before starting the backswing and throughout the stroke. After making contact, the player sustains this focus on the spot where the ball was for an additional 200 milliseconds, known as QE dwell time. Crucially, researchers have claimed that QE duration can differentiate between successful and less successful performances, even among experts (Wilson et al., 2016). However, these results are not unequivocal as Mann et al.'s (2011) found QE durations between successful and unsuccessful putts did not vary for both low and high handicap groups. Additionally, van Lier et al. (2010) discovered that optimal QE duration (defined to have ended when initiating the backswing) was not associated with performance. Similarly, when practitioners have tried to apply these findings, with elite golfers, results have been mixed (Farrow and Panchuk, 2016). In particular, it has proved difficult to explain why, across multiple putts, the same QE duration can lead to both success and failure (Farrow and Panchuk, 2016). Consequently, in an effort to gain greater insight into the processes supporting successful putting, the current study investigates performance using a multi-methods approach that combines eye tracking with a measure of neural activity derived from scalp recorded EEG.

Investigating neural activity within the pre-motor preparation phase has already shown some promise as a method for discriminating between successful and unsuccessful performance. Currently, the brain waves mainly explored in golf putting in the frequency domain are the theta band (4–7 Hz), the alpha band (8–12 Hz), the beta band (12–30 Hz), and the sensorimotor rhythm (SMR: 12–15 Hz). Superior golf putting performance has been linked to changes in relative theta power (Reinecke et al., 2011; Kao et al., 2013; Chen et al., 2022). For instance, Kao et al. (2013, 2014) discovered that midline theta power (i.e., FZ, CZ, PZ, OZ sites) was significantly lower for the best 15 putts compared to the worst 15 putts in a sample of professional and amateur golfers (handicap not stated, $n = 12$). Reinecke et al. (2011) observed that superior performance was associated with an increase in theta power over the left frontal scalp (electrode F3, however, only used F3, Fz, F4 in their analysis) with golfers who had an average of 7.9 ± 6.4 handicap (considered immediate skilled, $n = 20$). Critically, as well as the differences in skill level, the definition of superior performance may have differed across the studies: the Kao et al. studies used holed putts, whereas, Reinecke et al. (2011) did not state a direct performance measure. Also, the timings of the epoch varied across these studies: Reinecke et al. (2011) used an average across the putting period (2 min), whereas Kao et al. used −3 s prior to initiation of the movement.

There are also mixed findings in studies employing neurofeedback training to encourage superior performance, revealing both a decrease in frontal midline theta (Fmθ) power in three highly skilled (handicap = 0) golfers (Kao et al., 2014) and a significant reduction in theta power (Chen et al., 2022). In contrast, superior performance without neurofeedback training was associated with a notable increase in theta power (Chen et al., 2022). Although Chen et al. (2022) did try and match the skill level across the group, the variation in skill level (reflected in the high standard error) within each group must be considered when interpreting the findings. For example, the function specific group ($n = 12$, mean handicap $= 12.00 \pm 11.02$) exhibited much greater variation than either the traditional instruction group ($n = 12$, mean handicap $= 14.00 \pm 7.38$) or the sham control group ($n = 12$, mean handicap $= 18.00 \pm 8.86$). Nonetheless, taken together, the existing findings provide evidence that successful putting performance is associated with changes in theta power, specifically over frontal recording electrodes.

Following previous findings, the current study aims to gain clarity on the direction of the theta effect, and specific timings of the modulations throughout the pre-preparation period related to performance, when considering a sample of highly skilled golfers. Furthermore, through using the multi-measure approach we would like to gain insight into underlying cognitive and neural mechanisms governing action preparation (Gallicchio et al., 2017). For example, in golf putting, lower Fmθ levels may suggest reduced mental engagement, according to Kao et al. (2013, 2014) in professional and highly skilled golfers. A reduction in mental engagement seems in contrast to the response programming explanation (Williams et al., 2002) which is the dominant proposal as to how and why QE duration works (Walters-Symons et al., 2017). Aligned with the response program explanation, a longer QE enhances performance due to a longer period for cognitive programming (Vickers, 1996; Williams et al., 2002; Vickers, 2007). To help gain insight into the timings and potential link to QE durations, our study aims to explore fluctuations in theta power throughout the pre-putt preparation period using both the whole length of the pre-putt preparation period (−3 s) and at 500 ms time intervals.

Modulations in the alpha band have also been found to be associated with improved golf putting performance in a mixed sample of expert and novice golfers (Cooke et al., 2014). As with theta, however, there remains uncertainty regarding the direction of the alpha effect. For example, studies have reported both an increase (Baumeister et al., 2008) and a decrease (Babiloni et al., 2008; Cooke et al., 2014) in alpha power over frontocentral recording sites for successful compared to unsuccessful putts. It must be acknowledged that differences in skill level may be contributing to the ambiguity in the findings as the expert group in Baumeister et al. (2008) had large variations in skill level (average handicap = 8.3 ± 7.5). It could be argued the sample was more homogeneous in the Babiloni et al. (2008) and Cooke et al. (2014) studies, as participants in Babiloni et al. (2008) regularly competed in national and international competitions and practiced at least five times a week (no formal handicap was stated) and in Cooke et al. (2014), participants had a golf handicap < 5 (average handicap = 1.50 ± 2.32). Discrepancies in findings may arise from variations in task design (e.g., examination of expert vs. novice/expert golfers), the specifics of the analysis (including epoch duration and electrode selection), and the specific analytical methods employed. It is important to note that in Cooke et al. (2014, 2015), the size of the hole was adjusted, and was reduced to half its original size for expert participants, whereas a standard hole size was used in Babiloni et al. (2008) and Baumeister et al. (2008). Another significant observation is that alpha modulation may change throughout the pre-shot period. For instance, Cooke et al. (2014) identified a two-phase pattern of alpha oscillations among expert golfers, characterized by an initial increase followed by a sudden decrease in alpha power in the last second before movement initiation. Our study, therefore, aims to explore fluctuations in alpha power throughout the pre-putt preparation period, examining the whole length of the pre-putt preparation period (−3 s) in 500 ms time intervals.

Successful performance has also been associated with a greater reduction in beta power in the last seconds preceding golf putts (Cooke et al., 2014). While these findings are from a single study (and one that only analyzed limited electrode sites F3, Fz, F4, C3, Cz, C4) they align with broader evidence suggesting a decrease in beta power relative to baseline in sensorimotor tasks, particularly in tasks requiring accuracy (Kilavik et al., 2013). It has been suggested that this reduction in beta power may reflect the activation of sensorimotor networks (Pfurtscheller and da Silva, 1999), indicating beta involvement in the planning, processing, and execution of actions, including their sensory and cognitive aspects (Pfurtscheller et al., 2003). Consequently, and following the findings of Cooke et al., in the present study we will examine changes in beta power throughout the pre-putt preparation period, but with a larger array of electrodes (31 channels) across the scalp.

To the best of the authors' knowledge, the only studies examining sensorimotor rhythm (SMR) have been neurofeedback studies, including those by Cheng et al. (2015), who recruited 16 elite golfers (average handicap = 0 ± 3.90), and Wu et al. (2024), who recruited 44 professional golfers. In both studies, SMR neurofeedback training was found to enhance performance, with participants who received the training exhibiting greater SMR power (at Cz for Cheng et al., 2015, and Cz & CPz for Wu et al., 2024) compared to the control group. Here it is notable that the samples examined are homogeneous across the two studies, which aids comparison and may have contributed to the consistency in findings. These results are encouraging, especially given there are differences in the methodologies employed between the two studies. Nonetheless, in Cheng et al. (2015) it remains uncertain whether putt distances might have influenced the outcomes, as they were individualized and not reported. This lack of standardization means that distances could have differed between the control and intervention groups. Additionally, performance in Cheng et al. (2015) was measured using error distance, rather than counting holed putts. In contrast, Wu et al. (2024) standardized the distance across all trials. Furthermore, they (Wu et al., 2024) assessed performance by asking participants to putt towards a hole and record the percentage of successful putts, which is more representative of competitive golfing scenarios. At this stage, further study is required to gain greater insight into SMR and performance.

Another form of electroencephalography (EEG) analysis that sheds light on the processes involved in planning and preparing voluntary motor movement is the Movement-Related Cortical Potentials (MRCP) (Shibasaki and Hallett, 2006). The change in amplitude of MRCPs over time is typically regarded as an index of motor preparation (Wright et al., 2012). The readiness potential (RP) is a marker of particular interest to study. The RP is an event-related potential that consists of a negative deflection in EEG that begins around 2 s before self-initiated movements (Shibasaki and Hallett, 2006). Two studies (Mann et al., 2011; Xu et al., 2021) have analyzed neural activity in golf putting using MRCP and RP relative to performance. The results have been inconsistent across the two studies, however, critically there were skill level differences within the participants recruited. Mann et al. (2011) included both experts (n = 10, average handicap = 1.20 ± 1.23) and near-experts (n = 10, average handicap = 11.30 ± 0.82), whereas Xu et al. (2021) examined 21 novice golfers. Mann et al. (2011) did not find any significant differences in MRCP amplitudes between successful and unsuccessful putts (analyzing C3, Cz, C4, P3, and P4 separately). By contrast, Xu et al. (2021) did report performance-based differences, with greater increased negativity for successful in comparison to unsuccessful putts; however, clear RP (Cz) were not evident in their figures presented. In addition, both of these studies used electrooculogram (EOG) data to measure gaze behavior (rather than an eye tracker). There were, however, substantial differences in the putting paradigm employed across these studies. In Mann et al. (2011) the golfers putted to a standardized hole from 12 ft., whereas in Xu et al. (2021) golfers putted the ball into a modified hole from 2 m. In this case the center of the hole had a radius of 5 cm rather than the standard 10.4 cm. Outside the hole, however, there were three imposed concentric circles with radii of 10, 15, and 20 cm. A "hit" was recorded if the golf ball went into the hole or circle and a "miss" was recorded if the golf ball went outside the outermost circle to balance the ratio of the two conditions. At this stage, given the methodological inconsistencies and the variation of skill level further research with a homogenous sample of expert golfers is merited before conclusions can be drawn.

Our study aims to assess whether QE duration and neural activity can be used as reliable markers associated with successful putting in highly skilled golfers. This study therefore addresses two specific hypotheses: (i) there will be a difference in QE duration as a function of performance, and (ii) successful performances will be distinguishable from unsuccessful performance based on neural activity. Given our interest in highly skilled golfers, our theoretical starting point for the expertise-based differences in neural activity was informed by the neural efficiency framework (Del Percio et al., 2009) and previous research. We therefore predicted that successful performance would be associated with greater suppression of frontal theta, an increase in alpha power (high band 10–13 Hz), greater suppression of beta (Cooke et al., 2014) and an increase in SMR power. In addition, for the RP, we predicted that performance related differences would be observed, with less negativity for successful putts in comparison to unsuccessful putts.

2 Materials and methods

2.1 Participants

Twenty-eight participants (20 males, 8 females), all of whom were right-handed, with normal or corrected vision, were included in the study. The mean age of the participants was 24.2 years (±6.4), and the average handicap was +1.7 (±6.4). On average, participants had been playing golf for 12.8 years (±5.69), practiced for 15.5 h per week (±11.5), made 31.3 putts per round (±2.84), achieved greens in regulation 56.2% of the time (±10.1), and scored an average of 85% (±21.1) from 6 feet straight. For the sample of 12 participants included in the analysis of the EEG data (4 females, mean age 21.6 years ±5.4, average handicap +1.5 ± 4.4) participants had been playing golf for an average of 12.2 years (±6.54), practiced for 16 h per week (±12.5), made 31.1 putts per round (±3.10), achieved greens in regulation 57% of the time (±10.6), and scored an average of 88% (±21.6) from 6 feet straight.

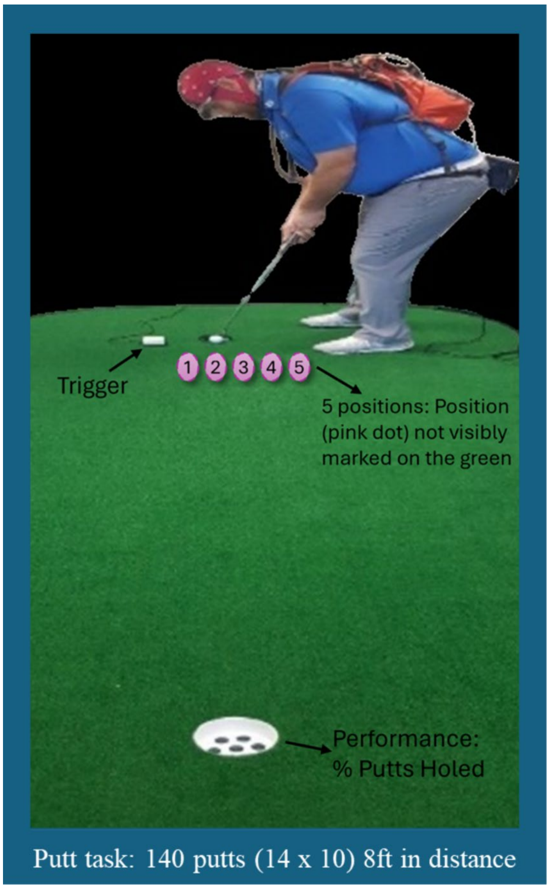

FIGURE 1
An image of a participant using the mobile equipment (eye tracking and EEG) whilst completing the putting task.

2.2 Protocol

Participants attended testing sessions individually. They were fitted with a mobile eye tracker (ASL XG Mobile Eye Tracker) and EEG system comprising 32 Ag/AgCl electrodes fitted in an elastic cap according to the 10–20 International montage and connected to a portable amplifier (ANT-neuro, Enschede, The Netherlands). Calibration of the eye tracker was performed using five colored markers positioned near the participant's feet while standing in a putting posture and addressing a golf ball. During calibration, participants were instructed to adopt a normal putting stance and maintain their gaze steady on the center of each marker, in a pre-designated order, for a duration of 100–200 ms. Participants used their own putter and Srixon AD333 Tour golf balls throughout the eye tracker calibration and the putting task. At the beginning of the putting task, participants completed a standardized warm-up protocol consisting of 12 practice putts, including 6 straight and 6 sloped putts, on an indoor artificial surface with a stimp meter rating of 10.2. Following the warm-up, participants completed a putting task (see Figure 1) involving 140 straight putts taken from a distance of 8 feet (2.4 m) from 5 different putt positions (5 cm apart). The putts were taken in blocks of 10 and randomization was applied within each of the seven blocks, with the constraint that they putted twice from each location in each block of ten putts. Each participant had a different order. The putt position was marked on the surface with a UV light so there were no obvious markings on the putt surface to slow down the learning of the positions. Re-calibration of the eye tracker occurred at the start of each putting block and whenever necessary (e.g., after a pupil recognition loss >100 ms or if the calibration had been lost).

2.3 Measures

2.3.1 Task performance

Performance was assessed by the number of successful (holed) putts. Professional golfers, on average, have a probability rate of 50% success from 8 ft (PGA Tour, 2024).

2.3.2 Quiet eye measures

Visual search behaviors were examined using EyeVision software (ASL Results Pro Analysis, formerly Argus, ASL) installed on a laptop (Dell Inspiron6400) captured at a frame rate of 30 Hz. All analyses were conducted post-testing. The onset of Quiet Eye (QE) had to occur before movement initiation of the backswing but could continue through the putting movement (Causer et al., 2017). QE offset was determined when gaze deviated from the target (ball or fixation marker) by more than 3° of visual angle for longer than 100 ms (Vickers, 2007).

2.3.3 EEG features

EEG data were recorded with a sampling rate of 500 Hz, a 0.016–250 Hz bandpass filter, and a notch filter set at 50 Hz. The electrode

AFz served as the ground and CPz as a common reference site. Electrode impedance was measured prior to each recording session and set below 10 kΩ using electrode gel. Similarly, impedances were checked throughout the session to maintain <10 kΩ. To timestamp the event of contact between the ball and putter, an acoustic box was connected to the EEG amplifier and a trigger code was sent via an acoustic box designed to capture the sound when the putter made contact with the ball. Although identifying the point of contact as time point zero means that some movement will be included within the pre-shot epoch, the alternative of timestamping the initial onset of movement is not sufficient for capturing the QE period (which onsets before movement initiation and continues after movement initiation (cf. Walters-Symons et al., 2017). The raw EEG data was first visually inspected, and portions of data outside of the putt periods and characterized by noise spread across all electrodes (due to transient changes in electrode impedance related to participants movements) were discarded. The electrodes (with the exception of prefrontal sensors FP1, FPz, and FP2) displaying abnormal power spectral activity (+/− 3 SD from mean signal recorded across included electrodes) were spherically interpolated using neighboring sensors signals. On average, 3.6 (SD = 1) electrodes were interpolated across participants. A 1 Hz to 30 Hz bandpass filter was applied (filter order: 1600, −6 dB, cut-off frequencies: 0.5 and 30.5 Hz) to the EEG signals. The data was re-referenced to the averaged electrodes. The filtered data then underwent a two step cleaning process aimed at parsing signals of artifactual sources (non-brain) from actual neural activity. In a first step, the filtered data was segmented into consecutive, non-overlapping one second segments. The signals of segments that were above or below three standard deviations from the overall mean of all segments were discarded. An extended infomax Independent Component Analysis (ICA; Makeig et al., 1996) was performed on the remaining data, with parameters adjustments to consider the rank deficiency of the data following average re-referencing and channel interpolation. The resulting Independent Components (ICs) were classified into categories using the IClabel (Pion-Tonachini et al., 2019). As a second step, the weights of the ICA decomposition were back projected to the filtered data (prior to rejecting one second segments). The ICs flagged as originating from muscles, eyes, line noise, and other non-brain sources by IClabel with a probability threshold above 70% were discarded. This resulted in the rejection of an average of 12 ICs (SD = 3). The proportion of remaining IC components after parsing non brain sources is in line with the guidelines proposed by Klug and Gramann (2021). This approach allows a more thorough but restrictive preprocessing to be applied as a first step (to ensure the quality of the ICA decomposition) and a less constraining approach to be employed during subsequent data processing steps. Following these processing steps, 3.5 s epochs were extracted (3 s pre contact and 500 ms post contact).

2.4 Data analysis

In all analyses statistical significance threshold was set at alpha = 0.05. To establish if there was a performance difference in QE, a paired *t*-test was conducted comparing mean QE duration for successful and unsuccessful putts.

An extraction of event-related spectral perturbation (ERSP; Makeig, 1993) features was performed through a time–frequency decomposition of the epoched data through the convolution of complex Morlet wavelets. The number of wavelet cycles ranged from 3 to 30 following a 0.8-step increase to estimate frequencies ranging from 3 to 30 Hz in 54 linearly spaced frequency steps. The spectral power at each frequency was baseline-corrected using a decibel (dB) transform relative to a baseline period of 500 ms (−3 to −2.5 s) prior to the period of interest (−2.5 s to 0 ms) performed on a single-trial basis (Grandchamp and Delorme, 2011). For ERSP analysis, the *a priori f*requency bands were selected based on the wider cognitive neuroscience and sporting literature, as follows: Theta (4–7 Hz), Alpha (8–12 Hz), Alpha Low (8–10 Hz), Alpha High (11–13 Hz), SMR (12–15 Hz) and Beta (12–30 Hz). The changes in overall power over the investigated frequency bands were then extracted for 5 consecutive time bins of 500 ms between the baseline period and the putt onset. In accordance with Del Percio et al. (2009) who adopted a neural efficiency framework approach, a series of Repeated Measures (2 × 5) ANOVAs with factors of Performance (Successful/Unsuccessful), Time (−2,500 to −2000 ms, −2000 to −1500 ms, 1,500 to −1000 ms, −1,000 to −500 ms, −500 ms to 0 ms) were separately carried out at each electrode cluster (Frontal: F3, Fz, F4/Central: C3, Cz, C4/Parietal: P3, Pz, P4), for each frequency band [theta, alpha (including low/high), SMR and beta].

For the Readiness Potential analysis, the continuous data sets were epoched around the onset of experimental events (−4,000 ms to 1,000 ms around putt onset). Consistent with the ERSP analysis, the epoched data were then baseline corrected by subtracting the mean voltage recorded within the 500-ms baseline period (−3 to −2.5 s) from the signal for each electrode and each trial. Averaging across epochs resulted in the creation of ERP waveforms for each individual electrode. These waveforms were then average across frontal, central and parietal clusters of electrodes. For each cluster, the readiness potential amplitude was computed as the mean voltage (in microVolts) of the ERP waveforms recorded within two successive 500 ms-long *a priori* time windows ranging from −1,000 to 0 ms prior to putting onset. Finally, statistical analyses were carried out at each electrode cluster (frontal/central/parietal) examining the extracted readiness potential features using a Repeated Measures (2 × 2) ANOVA with factors of Performance (Successful/Unsuccessful), Time (−1,000 to −500 ms, −500 to 0 ms) was separately carried out at each electrode cluster (frontal/central/parietal). All statistical testing was implemented in JASP version 0.6.13 (JASP Team, 2023).

3 Results

3.1 Performance

Performance was 69.71% (SD = 6.71%) for the sample of 28 participants. Performance for the sample of 12 participants included in the EEG sample, was 69.61% (SD = 7.37).

3.2 QE duration and performance

The mean QE duration for successful putts was 0.86 s (*SD* = 0.357 s) and 0.89 s (*SD* = 0.486 s) for unsuccessful putts for the sample of 28 participants (Figure 2). There was no difference in mean QE duration [$t_{(21)} = -0.670$, $p = 0.510$, $d = -0.143$]. For the sample of 12 participants included in the EEG sample, average QE duration for successful putts

($M = 0.71$, $SD = 0.18$) and for unsuccessful putts ($M = 0.68$, $SD = 0.14$). There was no difference in mean QE duration [$t_{(21)} = 0.454$, $p = 0.653$, $d = 0.140$].

3.3 Neural activity and performance

After the cleaning and processing stages, only 12 participants were retained with an average of 58 (SD = 8.91) successful trials and 25 (SD = 6.12) unsuccessful trials. The 500 ms post putt was removed from the analysis due to noise. The time frequency analysis, revealed a performance*time interaction [$F(4, 44) = 3.125$, $p = 0.024$, $n^2 = 0.041$] for theta (Figure 3) in the frontal cluster (F3, Fz, F4). As seen in Figure 3, in the last three time windows (−1,500 ms to 0 ms) unsuccessful putts exhibited an increase of theta power in comparison to the theta power for the successful putts. None of the *post hoc* tests were significant within this RM-ANOVA, although the final time window (−500 ms to 0 ms/contact) was close (i.e., $p = 0.07$). The RM-ANOVA for theta at the central cluster (C3, Cz, C4) did not reveal a significant difference in performance or a performance*time interaction. The RM-ANOVA for theta at the parietal cluster (P3, Pz, P4) did not reveal a significant difference in performance or a performance* time interaction.

The RM-ANOVA comparing alpha (8–12 Hz) in frontal/central/parietal clusters, did not reveal any significant differences or interactions (Figures 3, 4). Additional analysis using low (8–10 Hz) and high (11–13 Hz) bands of alpha was also conducted for each of the frontal/central/parietal clusters. The analysis did not reveal any significant differences or performance*time interactions however, the main effect for performance for low alpha in the frontal cluster (F3, Fz, F4) was close (i.e., $p = 0.06$). The RM-ANOVA comparing the SMR in central/parietal clusters also revealed no significant differences or interactions. Regarding beta (central cluster), there was a main effect for performance [$F(1,11) = 6.516$, $p = 0.027$, $n^2 = 0.093$], with a greater suppression (mean difference of −0.484 ± 0.190 dB) for successful putts in comparison to unsuccessful putts (Figure 4). There was no performance*time interaction. The RM-ANOVA revealed no significant differences in beta power at parietal sites (cluster P3, Pz, P4) or frontal (cluster F3, Fz, F4).

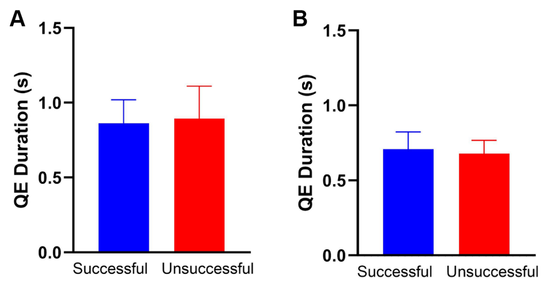

FIGURE 2
There are no performance-based differences in mean QE duration for either the full sample ($n = 28$, **A**) or the subset ($n = 12$, **B**) included in the EEG analysis. The error bars on both **(A,B)** are 95% CI.

Time analysis revealed a clear readiness potentials in both conditions at the frontal cluster with differences for successful shots in comparison to unsuccessful shots (mean difference = 1.706 ± 0.679 dB), as the RM-ANOVA revealed a main effect of performance [$F(1, 11) = 6.304$, $p = 0.029$, $n^2 = 0.248$], with unsuccessful putts having a greater negative amplitude in comparison to successful ones (Figure 5). The RM-ANOVAs for central and parietal clusters did not reveal any significant effects or interactions.

4 Discussion

The current study aimed to address the hypotheses that successful performance can be distinguishable from unsuccessful performance based on QE duration and neural activity. We found there was no difference in mean QE duration based on performance (holed putts vs. missed putts). The mean durations of quiet eye (QE) phases alone may not reliably indicate expertise. Critically van Lier et al. (2010) and Mann et al. (2011) also did not find QE duration differed based on expertise. It is worth noting the QE durations were lower than the optimal QE duration 2–3 s recommended for putting (Vickers, 2007), highlighting the potential need for a training intervention to achieve optimal QE duration. Consistent with our findings, van Lier et al. (2010) found without training, golfers had QE duration less than the recommended duration. By integrating eye tracking with EEG data, a deeper understanding can be gained regarding why identical QE durations can result in either successful or unsuccessful putts, as well as shedding light on the timings of optimal QE and the merits of teaching a QE intervention by examining the 3 s prior to contact. For instance, our findings reveal that successful putts exhibit distinct neural activity profiles compared to unsuccessful putts. Successful putts revealed a greater suppression compared to unsuccessful putts. The greater suppression in successful putts may signify activation of sensorimotor networks, indicating enhanced movement planning.

Additionally, performance differences in theta frequency were noted in the frontal region, with successful putts displaying a tendency for lower theta power, particularly in the final time window, compared to unsuccessful putts. Increased theta power for unsuccessful putts may indicate hesitation or the need for an adjustment to the motor plan prior to execution, resulting in inefficiency and extra cognitive demands, in line with the neural efficiency framework (Del Percio et al., 2009). These findings are also consistent with the findings of a meta-analysis by Filho et al. (2021) examining self-paced sports that provided support for the neural efficiency framework, specifically a decrease in theta was linked to optimal performance. From an applied perspective, our findings shed light on the timings and nuances to the process of putting outlined by Mann et al. (2011), when putting, players must maintain the intended putt line in working memory while focusing on the ball. They must then activate a motor program to accurately strike the ball with the necessary force and direction for the desired outcome (Mann et al., 2011). If there is a disruption in motor planning or lack of commitment to the first intended motor plan, then this will disrupt the performance. Here, we found greater suppression of beta activity in the central region during

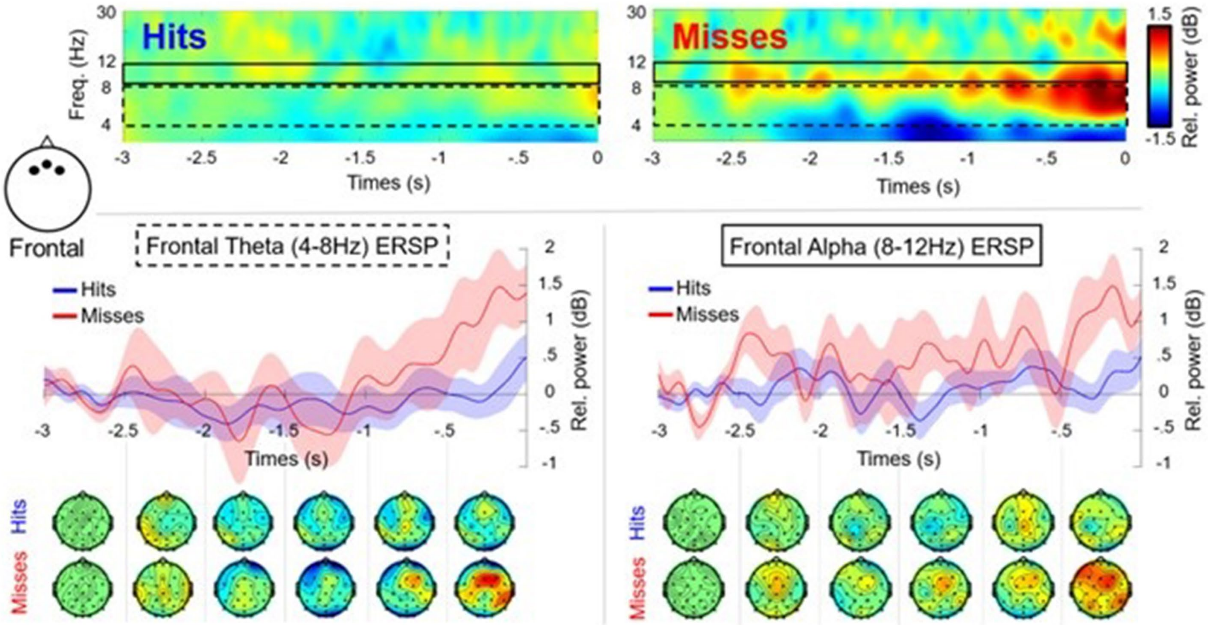

FIGURE 3
Time frequency plots and scalp maps showing theta (4–7 Hz) and alpha (8–12 Hz) oscillations for the frontal cluster (F3, Fz, F4) in the pre-motor preparation period (–3,000 ms to 0 ms) for successful (Hits: blue) and unsuccessful (Misses: red) putts (*n* = 12). There was a significant performance*time interaction for frontal theta power, but no other results were significant. The dashed black box highlights frontal theta activity with associated plot and topographic maps. The solid black line box shows frontal alpha activity with associated plot and topographic maps.

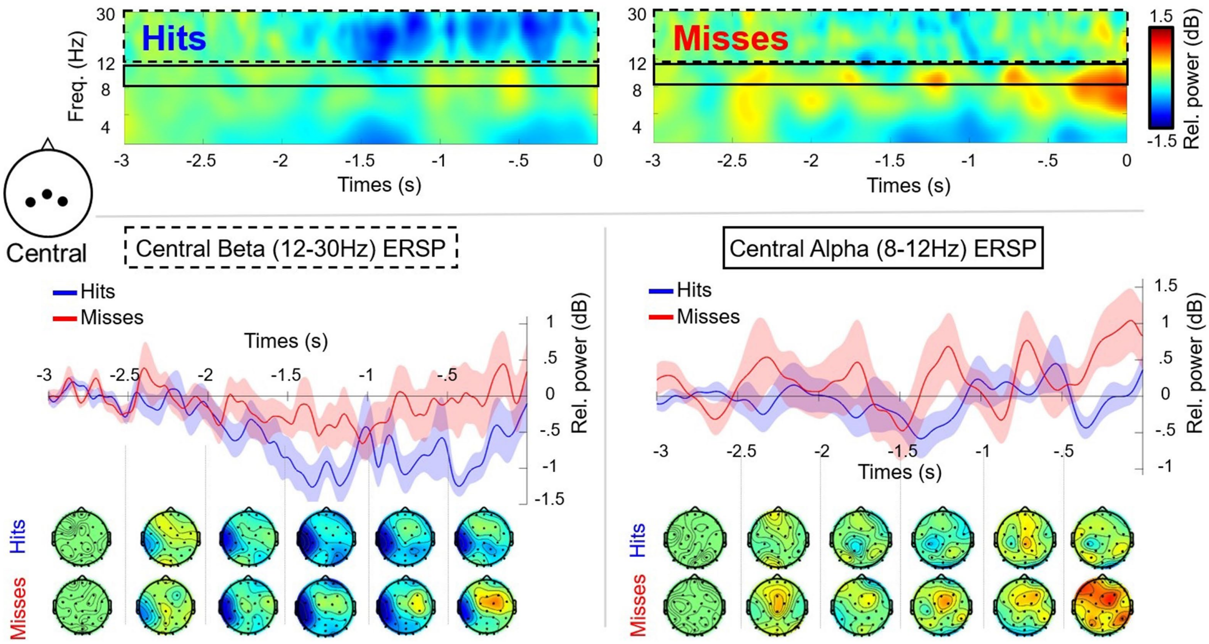

FIGURE 4
Time frequency plots and scalp maps showing alpha (8–12 Hz) and beta (12–30 Hz) oscillations for the central cluster (C3, Cz, C4) in the pre-motor preparation period (–3,000 ms to 0 ms) for successful (Hits: blue) and unsuccessful (Misses: red) putts (*n* = 12). There was a significant main effect for performance for central beta power, but no other results were significant. The dashed black box highlights central beta activity with associated plot and topographic maps. The solid black line highlights central alpha activity with associated plot and topographic scalp maps.

successful performance. In support of our findings, Tzagarakis et al. (2010) found the power decrease for beta during motor preparation was scaled relative to uncertainty, with the greatest reduction of power associated with certainty. Combined with the aforementioned theta findings above, this offers further support that unsuccessful putts are associated with uncertainty and

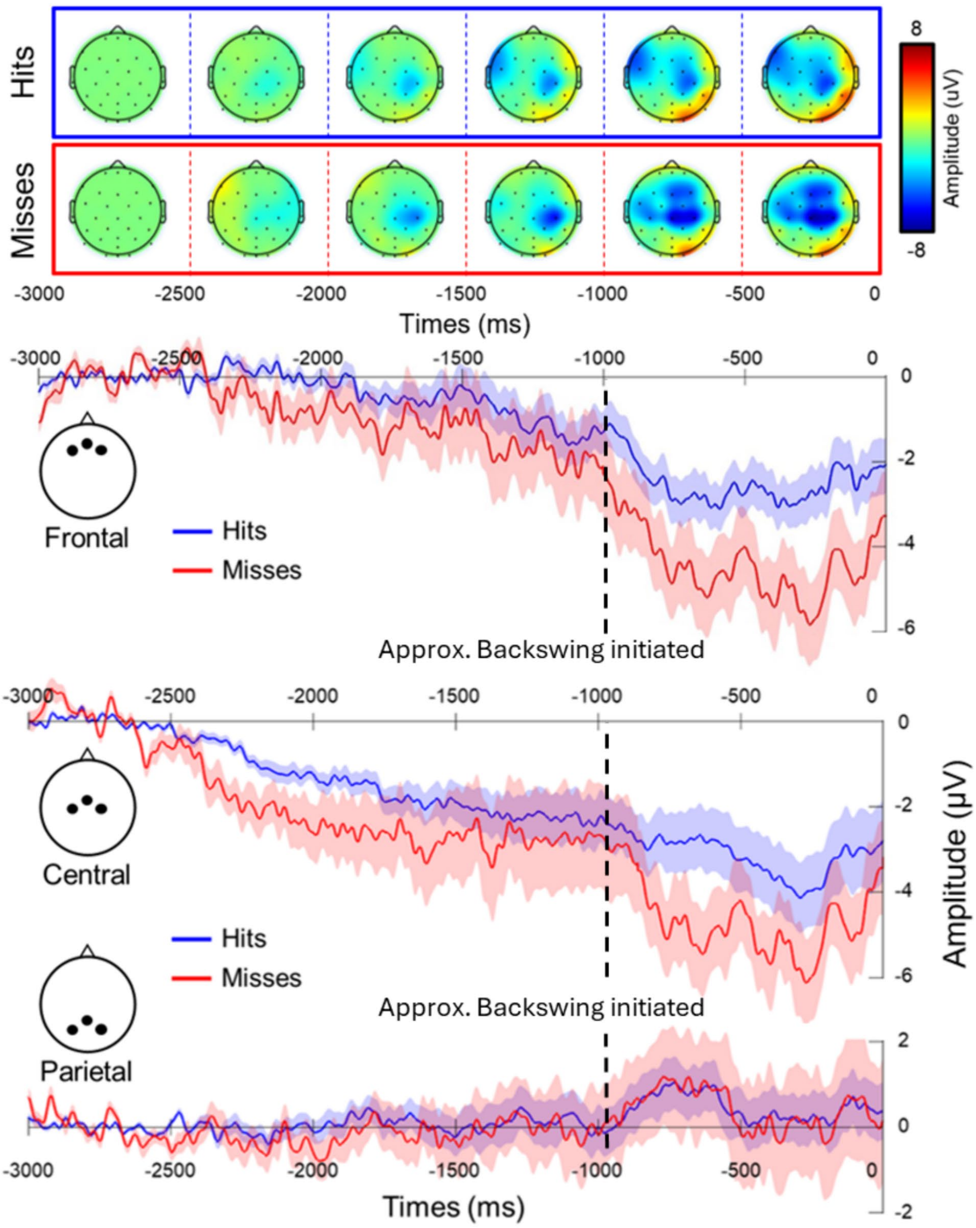

FIGURE 5
Differences in neural activity in the frontal cluster for successful (Hits: blue) and unsuccessful (Misses: red) putts for the readiness potential with associated plot and topographic scalp maps. The choice of trigger has limitations as the motor action (approximate initiation of the backswing represented by the black dashed line) can be seen as the trigger is aligned to contact (0 ms) not the initiation of the backswing.

hesitation, as the suppression (reduction in power) for unsuccessful putts was less than successful putts. The greater suppression for successful putts is considered an index of cortical activation (Tzagarakis et al., 2010; Kilavik et al., 2013). While it may not indicate more efficient activation on a neural level, we propose that greater beta suppression leads to enhanced preparation, which could be considered a form of increased efficiency. Additionally, we speculate that beta suppression may offer insight into the mechanisms underpinning QE duration, especially as the beta suppression onset timings for successful putts are consistent with recommended QE duration of 2–3 s (Vine et al., 2011). Furthermore, the monitoring aspects of theta may also offer insight towards the mechanism underpinning the proposed role of QE duration in continuous monitoring and online control (Gonzalez et al., 2017). Taking the findings together, we propose that neural activity may provide plausible insights into the mechanisms behind QE and how and why identical QE durations may lead to both successful and unsuccessful putts. Our findings offer working hypotheses and tentative explanations towards clarifying ambiguities regarding the efficacy of QE recommendations. Moving forwards, further research is required to support these claims.

Unexpectedly, our study did not find any performance-based difference in alpha power. These findings contrast with other studies where performance-based differences in alpha power were reported (Babiloni et al., 2008; Baumeister et al., 2008; Cooke et al., 2014) and do not align with the neural efficiency framework. Our research contributes to the ongoing discourse on the inconsistencies observed in alpha studies related to golf putting (Park et al., 2015). We advocate for further investigation into alpha power and performance during the pre-preparatory phase. Consistent with Pfurtscheller et al. (2003) we found the low and high alpha bands, (in our case low alpha) were more sensitive to performance differences so we recommend future research continues to adopt this approach. To facilitate comparison across studies, we recommend adopting standardized methodologies, including consistent epochs, task design, and data analysis approaches.

Our findings revealed that it is possible to observe performance-based differences, reflected in the amplitude of the readiness potential, with successful putts having a less negative amplitude in comparison to unsuccessful putts, in line with the neural efficiency framework (Del Percio et al., 2009). This finding offers support for the proposal that successful putts are associated with reduced response programming demands (Wright et al., 2012) requiring less energy (Di Russo et al., 2005). These findings may seem contradictory to the beta findings presented above, but recent research has suggested that beta and RP could reflect different phenomena within the movement preparation processes (Gavenas et al., 2023; Parés-Pujolràs et al., 2023). We recommend that future research explores how beta desynchronization in the motor cortex relates to the RP.

4.1 Limitations and future research

We propose the EEG findings are not trivial, as both the definition of experimental event in such a naturalistic context and the processing of neural data acquired while whole body motion was unrestricted posed substantial challenges. To address these challenges and to maintain good signal to noise data, we used a rigorous process for cleaning the EEG data and this did result in a high loss of data. Our study is not without limitations, especially as it is a single study with 12 participants and we would recommend further research with more participants, especially when using repeated measures ANOVAs. We used an acoustic trigger to timestamp the moment the club made contact with the ball, so the movement had to occur during the epoch, meaning that we could not accurately detect the initiation of the backswing. We suggest modifying the EEG data time stamping method to precisely capture both the contact point and initiation of movement, crucial for investigating readiness potentials, potentially utilizing lightweight accelerometers on equipment like clubs, if feasible without affecting stroke kinematics. Additionally, we recommend future research utilizes recent technology advancements that allow for the collection of synchronized eye tracking and EEG data acquisition and time stamp the EEG data through fixations (Ladouce et al., 2022). This approach would allow for the working hypotheses of the mechanisms underpinning QE to be explored in detail as a direct analysis of QE duration and EEG can be undertaken. For more detail on this approach and the potential of synchronized eye tracking and EEG data and the feasibility, including outlining current challenges with this approach, are discussed in Ladouce et al. (2017). We would also encourage future researchers to consider participant recruitment, design and trial numbers for a good signal-to-noise ratio. Recruiting a highly skilled sample has clarified some of the ambiguities in prior research regarding the directionality of power and we believe future research with an increased sample size would continue to strengthen the research in this area. Despite the challenges, we believe this study paves the way for further investigation of the neural correlates of sporting performance by showcasing methods to effectively capture neural dynamics of action planning in applied sporting contexts.

4.2 Practical implications

This study unveils the challenges encountered during EEG data collection in a practical scenario and proposes solutions to overcome these hurdles. While highlighting the benefits of this approach, it stresses the importance of methodological rigor, especially in EEG data analysis. Golf putting may serve as an applied context to delve deeper into the relationship between beta and MRCPs, specifically readiness potentials, to offer fruitful theoretical insights. Furthermore, the findings demonstrate tentative evidence to guide the efforts to unveil the mechanisms behind QE and clarify its effectiveness (Williams, 2016). We acknowledge that our findings stem from a single study, underscoring the need for future longitudinal studies with consistent methodological approaches to establish a more robust understanding of the relationship between neural activity and expertise. We understand the complexity involved in such research endeavors, both in terms of time investment and methodological intricacies. Nevertheless, we encourage researchers to embrace the multifaceted nature of the sporting domain (Bishop, 2008) when investigating markers of cognitive-motor expertise in golf putting and strive to develop practical recommendations. Only then do we believe it would be appropriate to provide recommendations for athletes, coaches, and practitioners.

Data availability statement

The original contributions presented in the study are publicly available. This data can be found here: DOI 10.17605/OSF.IO/D6483.

Ethics statement

The studies involving humans were approved by University of Stirling (School of Psychology and Natural Sciences). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

LC: Writing – original draft, Writing – review & editing, Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Visualization. GA: Methodology, Writing – review & editing. SL:

Conceptualization, Formal analysis, Visualization, Writing – review & editing. DK: Conceptualization, Methodology, Writing – review & editing. MB: Formal analysis, Methodology, Writing – review & editing. AH: Supervision, Writing – review & editing. DD: Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Influence of problem-solving ability and personality variables on the improvement and creativity of tactical decisions in basketball

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Background: Basketball players are increasingly required not only to read the tactical actions that take place in a game but also to make correct tactical decisions. This includes greater creativity in the type of solutions they must provide when faced with various tactical situations. To acquire these skills, young players need training in which personality and general intelligence variables significantly influence the learning process.

Methods: A Perceptual Tactical Training (PTT) program was implemented, correlated with the Eysenck Personality Questionnaire and the Raven's Progressive Matrices test, to observe improvements in tactical perception and decision-making among young basketball players.

Results: The PTT produced significant improvements in tactical solutions and tactical perception for all players. Players who scored high in general intelligence found it easier to perceive tactical situations but struggled to generate original tactical solutions. Conversely, players with high psychoticism and high general intelligence were more capable of creating innovative tactical solutions but did not excel in perceiving tactical game situations.

Conclusion: Therefore, it is crucial to be aware of the individual differences in intelligence and personality traits among young players to enhance their tactical decision-making and creative abilities.

KEYWORDS

basketball, creativity, TACTICS, perception, decision making, personality, general intelligence

1 Introduction

The issue of creativity in sport is becoming increasingly important, considering that tactical systems are more complex than ever before, information media are multiplying, and the mobility of athletes is increasing exponentially. This leads to a heterogeneity of sporting scenarios and game combinations due to the diverse geographical origins of the athletes on the same team [Milennium Derecho Internacional Privado (DIPR), 2021]. Although there are insufficient studies in this field, many underline the importance of developing operative thinking, usually called tactical thinking in the sports sphere, which is the premise of creative performance (Aydin, 2019a; Aydin, 2019b; Bowers et al., 2014; Santos et al., 2017). There is evidence that creativity strongly influences work and sport practice (Klatt et al., 2019; Memmert et al., 2010; Conesa-Ros and Angosto, 2017; Marín et al., 2012), although more research is needed in the latter field.

Araújo (2006) follows, to some extent, the research line of Mahlo (1975) regarding creativity, though he more frequently refers to the term operative or tactical thinking. Several works have been published on creativity in sport (Martínez-Vidal and Díaz-Pereira, 2008; da Costa et al., 2018; Runco and Pritzker, 2011; Richard et al., 2017; Richard and Runco, 2020), but few have shown the explicit interest of the present research in addressing the topic in both a social and formative manner simultaneously.

One of the most controversial and difficult issues to address in the field of tactical thinking and creativity in sports is the decision-making process required to handle complex tactical situations within limited time frames (Furley and Memmert, 2015). It is crucial to remember that responses in sports need to be the most appropriate, despite the speed with which they must be executed (Hüttermann et al., 2019; Karaca and Aral, 2017). According to Memmert (2015), the most interesting aspect is the conflict athletes often face in sports games: they seek comprehensive, representative, and dynamic responses (in tune with the rapid pace of actions during a match) without sufficient time to consider the best course of action. Acting too quickly risks efficiency, while aiming for the most efficient solution might render the response obsolete in an instant, making it ineffective.

Memmert (2015) highlight that incorporating variables of intelligence or intellectual capacity is essential when designing psychological interventions to enhance the processes of perception and mental solutions in sports situations that demand high creativity (Alarcón, 2008; Alarcón et al., 2010; Alarcón et al., 2017).

Following the important theme of attention in developing effective tactical perceptions, Hüttermann et al. (2019) found an association between sport-specific divergent thinking in relation to tasks that included videos of real game situations, which were compared with performances of football players divided into two groups, with different levels of experience (amateurs and professionals).

The study of intelligence aims to measure the general factor by providing direct information on the individual magnitude of certain cognitive functions (observation and reasoning) and an evaluation of nearly all of them, representing the general intellectual capacity or common denominator of the totality of intelligence operations (Raven et al., 1991). This is one of the reasons why this theory and its resulting procedure were chosen for the present study.

Eysenck's (1992) personality structure is a hierarchical model with four descriptive levels. The first level (the lowest) consists of observable and somewhat circumstantial responses that do not characterize the subject. The second level consists of habitual responses that the subject exhibits in similar situations. The third level includes behaviors that are habitually exhibited and can distinguish the subject, and the fourth level consists of general factors.

What is of interest is how athletes (in this case, basketball players) behave in certain ways in situations that demand selective perceptions, complex mental solutions, and, in a general sense, creativity that is supported not only by cognitive skills but also by dispositions and affective peculiarities. People with high scores in this dimension are more vulnerable to disorders traditionally called neurotic. These subjects may be more vulnerable to stressful situations, in which they are more likely to develop feelings of guilt, anxiety, low self-esteem, shyness, sadness, and emotionality (Pérez-Córdoba et al., 2003; Cantón et al., 2022). It is evident that the psychologist's control of neuroticism is of great importance in the sports context, which, by nature, subjects the athlete to constant ergogenic, competitive, and self-affirmative pressures. Athletes with high neuroticism may find it difficult to navigate such situations and impose a proactive, optimistic, and confident response. In general, people who engage in sports activities early on show fewer manifestations of neuroticism because they learn more effective adaptive resources. The opposite pole of this dimension describes the athlete as capable of emitting adaptive responses according to the demands.

Another dimension of Eysenck's model is introversion vs. extroversion, which is probably more commonly used in the area of sports because of its close relationship with levels of arousal and inhibition that are constantly tested in sports activities. Donado-Mazarrón (2019) analyzes that subjects with a high score in extroversion seek intense stimuli, take risks, and enjoy noisy environments. Conversely, subjects with low scores avoid stimulation, are cautious, serious, and prefer a type of life considered boring by extroverts. Hence, in sports, coaches and sport managers need to make good use of this scientific information on the personalities of athletes. Basketball is a good example in which the importance of this dimension in sports can be illustrated (González, 2019a,b).

Psychoticism is considered a dimension of normal personality, where extreme scores predispose individuals to psychotic disorders, bipolar disorder or schizophrenia, antisocial behavior, and psychopathy (Eysenck, 1992). The traits that characterize this dimension include aggressiveness, coldness, creativity, and impulsivity, as well as more controversial traits such as egocentrism and low empathy. There are several organic correlates associated with this dimension, but here we focus only on those that underline intelligence and creativity, in addition to the recognized sensation seeking of subjects with high psychoticism.

There is a predominant opinion that a certain presence of the psychoticism dimension in athletes contributes to increased creativity and instrumental aggressiveness necessary for good performance (Del Toro et al., 2013; González, 2019a,b), although some researchers have expressed doubts about this view (Iglesias, 2017).

2 Materials and methods

2.1 Ethical approval

Written informed consent was obtained from all participants prior to initiating the research. This study was approved by the Ethics Committee of the University of Sevilla and conducted following the guidelines established in the Declaration of Helsinki.

2.2 Participant

The sample consisted of 24 male basketball players aged between 16 and 17 years old, classified as juniors. They were purposefully divided into two groups: an experimental group comprising 16 members who underwent Tactical Perceptual Training (TPT), and a control group consisting of 8 members who received conventional training only over the course of thirteen weeks of TPT. The selection criteria for belonging to one group or the other was agreed with the coaches, who took into account that the control group should include players of all positions such as point guard, forwards and centre and that they should have average technical and tactical knowledge. All participants underwent both pre-experimental and post-experimental series of drills, with the results compared between the groups. Post-experimental testing using the Eysenck Personality Questionnaire (EPQ) was conducted for the control group after the conclusion of the study.

The selection of participants was based on purposive sampling of matched cases to ensure comparability between the experimental and control groups. All participants were exclusively male.

2.3 Variables

The study considered several key variables that influence the tactical and perceptual performance of basketball players:

2.3.1 Meaningful tactical perception (STP)

Meaningful Tactical Perception is defined as the ability to extract essential information from the tactical situation a player faces, abstracting from the superficial and unnecessary, and responding effectively in minimal time (Díaz Rodríguez, 2021).

2.3.2 Perceptual tactical training

Perceptual Tactical Training is defined as controlled exposure to images representing everyday situations in basketball games, aimed at developing meaningful tactical perception in the sport (Díaz Rodríguez, 2021).

2.3.3 Intellectual capacity: abstract thinking and reasoning by analogies

Regarding intellectual capacity, the approach by Raven et al. (1991) was utilized, which conceptualizes intellectual capacity to compare forms and reason by analogies, independent of acquired knowledge.

2.3.4 Neuroticism

Neuroticism follows Eysenck's (1992) perspective as a personality trait revealing low self-control, suggestibility, lack of sociability, and an inability for volitional effort. It is assessed on a graded scale from low neuroticism (absence of these characteristics) to high neuroticism, characteristic of individuals diagnosed with neuroticism.

2.3.5 Extroversion

Extroversion is defined according to Eysenck's (1992) framework as a personality trait revealing high sociability, communicativeness, and a favorable balance in arousal-inhibition processes. Extroverts tend to perform better in high-stress situations, while introverts excel in monotonous or low-demand situations.

2.3.6 Psychoticism

Psychoticism is conceptualized based on Eysenck's (1993) perspective as a personality trait revealing aggressiveness, coldness in the face of challenges, a tendency toward bizarre or unpredictable behavior, hostility, and divergent thinking. It is assessed on a graded scale from low (absence of these characteristics) to high, characteristic of individuals diagnosed with psychosis.

2.4 Instruments

2.4.1 Instruments for tactical perceptual training (TPT)

The TPT consists of images depicting 10 basketball players engaged in specific game actions requiring technical-tactical decisions. These images form an experimental series of 25 slides presented sequentially, each displayed for a very short period of time (maximum 3 s). As the sessions progress, the presentation time is reduced by 0.2 s until reaching a minimum exposure time of 2 s (e.g., 3 s., 2.8 s., 2.6 s., 2.4 s., 2.2 s., and 2.0 s.). The purpose of this controlled time reduction is to condition players to develop meaningful tactical perception, focusing on essential tactical information while disregarding irrelevant details, thus enabling them to formulate precise and effective responses in the shortest possible time. The instrument is structured around two main phases: (a) perception and analysis of the situation; (b) tactical decision-making. Its aim is to facilitate the spontaneous identification of critical cues that prompt accurate responses to each presented image.

2.4.2 Raven's progressive matrices test

The Progressive Matrices test (Raven et al., 1991) is designed to assess the "G" factor, which represents general intelligence essential for problem-solving across various cognitive tasks. The test emphasizes analytical reasoning, perception, and abstraction abilities through analogical reasoning, independent of specific cultural knowledge or prior experience. An example of a recent adaptation can be found in Te Nijenhuis et al. (2019).

2.4.3 Eysenck personality questionnaire (EPQ-R)

The EPQ-R is an administered test that evaluates three dimensions of personality:

- **Neuroticism (N):** Provides information on personal stability, anxiety levels, potential depression, and other related traits.
- **Extraversion (E):** Assesses sociability and arousal levels, ranging from lively and adventurous to quiet and withdrawn, with Introversion as its opposite.
- **Psychoticism (P):** Measures behavioral traits including aggressiveness, unconventionality, empathy, and propensity for conflict.
- **Self-portrait distortion scale (L):** Aims to assess response sincerity or comprehension level. Scores for each dimension are determined according to established test norms (Hernán-Gómez and de la Peña, 2018).

2.5 Procedure

The experimental design runs over thirteen consecutive weeks. The TPT was conducted three times per week (Monday, Wednesday,

TABLE 1 Experimental planning design.

Week 1	Week 2	Week 3	Week 4	Week 5
Monday Implementation sequence Pre-experimental	Block 1 *3 seconds*	Training break TPT *(just basketball court training)*	Block 2 *2.8 seconds*	Training break TPT *(just basketball court training)*
	Monday Experimental sequence 1 Feedback Sequence 1		Monday Experimental sequence 4 Feedback Sequence 4	
	Wednesday Experimental sequence 2 Feedback sequence 2		Wednesday Experimental sequence 5 Feedback sequence 5	
	Friday Experimental sequence 3 Feedback sequence 3		Friday Experimental sequence 6 Feedback sequence 6	

Week 6	Week 7	Week 8	Week 9
Block 3 *2.6 seconds*	Training break TPT *(just basketball court training)*	Block 4 *2.4 seconds*	Training break TPT *(just basketball court training)*
Monday Experimental sequence 7 Feedback sequence 7		Monday Experimental sequence 10 Feedback sequence 10	
Wednesday Experimental sequence 8 Feedback sequence 8		Wednesday Experimental sequence 11 Feedback sequence 11	
Friday Experimental sequence 9 Feedback sequence 9		Friday Experimental sequence 12 Feedback sequence 12	

Week 10	Week 11	Week 12	Week 13
Block 5 *2.2 seconds*	Training break TPT *(just basketball court training)*	Block 6 *2.0 seconds*	Friday Implementation sequence Post-experimental
Monday Experimental sequence 13 Feedback sequence 13		Monday Experimental sequence 16 Feedback sequence 16	
Wednesday Experimental sequence 14 Feedback sequence 14		Wednesday Experimental sequence 17 Feedback sequence 17	
Friday Experimental sequence 15 Feedback sequence 15		Friday Experimental sequence 18 Feedback sequence 18	

and Friday) in a classroom inside a school hall equipped with a projector. The test administration time was around 30 min. These days were designated because the players had training sessions with their team and could meet before the basketball training session. All individuals participated between September 2018 and May 2019, while the pre-design phase took place between September 2017 and August 2018.

Table 1 shows the partial planning of the work sessions, illustrating the distribution of sessions from the second to the fifth week, with the first week dedicated to the pre-experimental series. In week 1, the Raven's Progressive Matrices Test, the 2.4.3 Eysenck Personality Questionnaire (EPQ-R) and TPT were administered. In week 13, the TPT was retested and the results were compared. It is observed that if there is a higher score in the TPT results, there has been an improvement in tactical learning and connect it with the data from the questionnaires carried out in week 1.

The subsequent weeks maintain the same work pattern until week 12, during which all the experimental series are conducted along with their respective feedback sessions. In week 13, when the experiment concludes, a post-experimental series is carried out, following the same dynamics as the first week with the pre-experimental series.

TABLE 2 Regression analysis to determine the predictive value of progressive matrix test scores at various increments after receiving ETP.

Variable	R	df	F	p
Delta (increase) of accurate perceptions	0.581	15	7.134	0.018*
Delta (increase) of successes of successful mental solutions	0.358	15	2.052	0.174 (n.s.)
Delta (increase) of original mental solutions	0.494	15	4.508	0.05

*Indicates that the data confirm the improvement observed in the study.

2.6 Statistical analyses

The statistical procedures used were: Kolmogorov–Smirnov test to verify the normal distribution of the data; calculation of means, standard deviations and minimum-maximum intervals of correct perceptions for the two pilot groups; t-tests of differences between means, paired observations, to estimate the significance of the differences. By means of the simple regression analysis model, the predictive values of the personality qualities studied were studied.

2.6.1 Verification of the TPT working hypothesis

The working hypothesis was verified in two parts, corresponding to the two questions that the players had to answer for each slide:

- Tactical Perception: What is happening on the court at the moment?
- Tactical Solution: What tactical solution would you give to this situation?

The question related to the tactical solution takes into account the playing philosophy of both the player's own team and the opposing team.

For both parts, *t*-tests for differences between means (paired observations) were applied, as this test best suits the interest of confirming possible differences when dealing with an ordinal scale as used in this part of the research.

2.6.2 Validation of tactical perception

According to the results of the experimental group, the tactical perceptions and mental solutions were evaluated in each of the 25 pre- and post-experimental slides, and the values were recorded in a database for processing using SPSS version 24.

Descriptive statistics were obtained for each of the indicators referred to in this methodological chapter. The values obtained for each response of perception and mental solution were very similar to those obtained in the experiment itself, as will be seen later in the results chapter.

The t-test for differences between means (paired observations) was used to determine the differences in the number of correct tactical perceptions between the experimental group (who received the TPT) and the control group (who did not receive it), adopting a *p*-value equal to or less than 0.05 to determine those that were significant.

Additionally, using Pearson's rank correlation matrix, the number of correct tactical solutions was studied concerning the first question regarding the significant tactical perception, the PIR values, and those obtained in each of the performance rating scales, and the correlations were taken into account.

2.6.3 Validation of the tactical solution

To develop this objective, the 16 subjects of the experimental group were previously evaluated to determine the level of abstract thinking or reasoning by analogies (Raven's Progressive Matrices Test), and the degree of neuroticism, extroversion, and psychoticism using Eysenck's EPQ Test.

Subsequently, all evaluations regarding the tactical perceptions on each experimental slide (evaluated as correct or incorrect) and the solutions issued for each of them (evaluated as incorrect, incomplete, correct, or original positive) were collected.

Using the simple regression analysis model, the predictive values of the personality qualities studied with respect to each indicator of perception and mental solution for each slide were examined, adopting a *p*-value equal to or less than 0.05 to determine those that were significant.

3 Results

3.1 Results of abstract reasoning ability as a predictor of mental solutions

By means of a regression analysis (Table 2), it was observed that high scores in the Progressive Matrices Test in the experimental group that received the TPT were able to predict a greater number of successes in the tactical perception promoted by the slides.

The correct answers to the second research question, "What tactical solution would you give to this situation?" were not significantly associated this time with intellectual capacity *per se*, which reveals that without knowledge and active experience, intelligence does not advance much further. As shown in the following table, a regression analysis with the variable intellectual ability as a predictor did not reach statistical significance against the number of correct solutions as the dependent variable.

In other words, the ability to find relations through analogies and to develop abstract reasoning favors the identification of what is happening on the field but not the solution that is issued.

In the Table 2 regarding the result of a regression analysis to determine the predictive value of the Progressive Matrices Test on the increase of correctness in the phase of perception and analysis of the situations contained in the TPT slides, the aforementioned calculation revealed that the ability to develop abstract reasoning and thinking by analogies in the sample studied was able to predict significantly ($p = 0.018$) a better use of the TPT for the tactical perception phase.

As shown in Table 2, the better intellectual performance showed an interesting relationship with the ability to find originally positive solutions to the challenges imposed by the experimental series. The aforementioned relationship was significant ($p = 0.05$), which allows us to understand that intellectual capacity plays a role in identifying what is happening in the game scenario based on elements that deviate from the canons and expectations, incorporating elements of high originality into cognitive management.

TABLE 3 Matrix of correlations between personality variables (intellectual ability, neuroticism, extroversion and psychoticism) and correct and original solutions at the end of the thirteen weeks of ETP.

Variable	Raven	Neurot.	Extrov.	Psicot.	Sol. corr. post	O+Post
Raven	–	0.712	0.336	0.099	0.419	0.000
Neurot.	0.712	–	0.062	0.176	0.223	0.111
Extrov.	0.336	0.062	–	0.690	0.548	0.841
Psicot.	0.099	0.176	0.690	–	0.036*	0.122
Sol. Corr. Post	0.419	0.223	0.548	0.036*	–	0.100
O+Post	0.006**	0.111	0.841	0.122	0.100	–

p less than 0.05. *Indicates that Psychoticism showed a significant relationship with the number of correct solutions in the post-experimental evaluation. **Indicates that the score on the Progressive Matrices Test (abstract thinking or reasoning by analogies) was very significantly related to the number of original positive solutions provided in response to the slides after the experimental situation.

3.2 Results for psychoticism and other personality variables as predictors of tactical or mental solutions

As can be seen in the following Table 3, the personality variables that showed significant correlations with the Tactical Perceptual Training (TPT) results were abstract thinking and psychoticism, while neuroticism and extroversion were not significant.

The following aspects were tested:

- The Progressive Matrices Test score (abstract thinking or reasoning by analogies) was very significantly related to the number of positive originals emitted in front of the slides after the experimental situation.
- Psychoticism showed a significant relationship with the number of correct solutions in the post-experimental evaluation.

3.2.1 Personality variables and tactical performance

Personality variables also had a certain impact on tactical performance, as illustrated in the Table 3. It shows the correlations between the observable components of the final version of the performance scales for the experimental group and the two personality qualities that have shown the greatest influence in this study.

In addition to the greater benefits of TPT in the experimental group referred to above when analyzing the PIR values, these results will deepen the directions of improvement and are reflected in the correlations below. Considering that these scales were evaluated by experts using ordinal statistics, a study of correlations made it possible to specify the particular benefits of TPT on these scales.

3.2.2 Neuroticism, extroversion, and performance rating scales in the experimental group

The variables neuroticism and extroversion did not show the same significance in the present study as intelligence and psychoticism (Table 3). This does not mean that they lack influence on the behavior of the athletes; it only seems to indicate that when testing the cognitive capacity necessary to discern what happens in an interactive, synergistic, and complex tactical context such as in basketball games (and to do so in conditions of more intense time deficit than in real practice, as in the case of those arranged in the last three weeks of the TPT: times of 2.4, 2.2, and 2.0 s), these variables do not play the role of intelligence and psychoticism.

4 Discussion

The primary objective of this study was to examine how problem-solving ability and personality variables influence the improvement and creativity of tactical decisions in youth basketball players.

The results indicated that the Perceptual Tactical Training (PTT) program led to significant improvements in both tactical solutions and tactical perception for all players. Additionally, players with higher abstract reasoning ability demonstrated greater efficiency in perceiving tactical situations, while those with high levels of psychoticism and general intelligence were more capable of generating innovative tactical solutions.

Regarding abstract thinking, its relevance for the development of technical and tactical skills is acknowledged (Aydin, 2019a). Although it is not a sufficient condition for developing the levels of creativity needed in specific activities such as sports and, above all, for achieving significant tactical perceptions of high quality and speed, it is clear that having medium to high intellectual capacity facilitates the use of Tactical Perceptual Training (TPT). However, without theoretical-tactical knowledge and active sporting experience, an intelligent athlete would not be able to access the tactical concept presented with the relevance of an expert, as is needed in competitions. Creative thinking is nourished by this basic intelligence, which becomes a premise for reaching higher levels of tactical thinking (Araújo, 2006).

Intelligence endowed with the aforementioned knowledge and skills may not be enough to achieve the expression of talent that ensures success; other personality characteristics are needed. Psychoticism appears in the present study to be significantly associated with the number of successful tactical perceptions under time constraints during the game days (Araújo, 2006).

Several of the seven factors that make up the classic psychoticism dimension of Eysenck and Eysenck (2008) stand out as potential contributors to the creativity stimulated by the designed TPT: impulsivity, antagonism, and non-conformism. Others related to the low socialization of subjects with high psychoticism were not taken into account here, as they do not fit the essentially cognitive approach to the research. However, the three mentioned are sufficient to support the creative projection that allows the use of the perceptual tactical training that the basketball players examined here received.

According to Pelechano (1997), people with high psychoticism can be original in this process of coordinated activation of cognitive resources, which memory stores in a relatively passive way. The contribution of psychoticism includes the so-called non-inclusive style of thinking (Pelechano, 1997) and a larger arsenal of ideas on which to build a conclusion, which allows for the emergence of more innovative, rare, and creative responses than those with a more conventional approach to the problem. This may be part of the basis of creativity, associated with the psychotic dimension.

The relationship between psychoticism and so-called creative achievement in artists has been tested. Götz and Götz (1979) found that artists had significantly higher psychoticism scores than non-artists, contributing to Eysenck's (1993) confirmation that real artistic achievement is associated with psychoticism. It is not difficult, then, to accept the scientific evidence that something similar occurs with high-achieving athletes. Top and Akil (2018) found that males who scored highest in scholastic, scientific/mechanical, and artistic creativity also scored highest in psychoticism.

However, research does not always support the role of psychoticism in sports activity; some studies report no significant differences between this variable and performance (Bernacka et al., 2016). One possible explanation is that those studies lacked the experimental character of the present one and were limited to descriptive/comparative studies of men and women, practitioners and non-practitioners, without delving into the essence of self-regulatory elements such as those that come into play when an athlete must interpret the content of a tactical slide, develop complex and rapid cognitive processes to detect relevant signals, and disregard accessory ones in the shortest time. In the post-experimental games, it was shown by a group of experts that these skills were also manifested in the specific sport activity.

Bernacka et al. (2016) have reported that the level of psychoticism was lower in weightlifters and ju-jitsu practitioners, although they acknowledge that in other studies conducted with women in combat sports, non-conformism, a trait closely related to psychoticism, appears with greater presence (Burdizicka and Goral, 2014, cited by Bernacka et al., 2016).

Another reason that may explain the scarce scientific attributions to psychoticism as a personality variable capable of generating creativity in athletes is that many authors do not study the dimension itself but rather indicators related to this dimension since the first and efficient studies conducted by Eysenck and other authors mentioned above. For example, greater instrumental aggressiveness and "toughness" have been observed in creative athletes, qualities clearly associated with psychoticism. Memmert (2011, 2015) has done relevant and sustained work on the possible ways in which creativity can contribute to the world of sport, defining it as "unusual, innovative, statistically rare, or even unique behavior in solutions to a sport-related situation" (Memmert, 2011, p. 373), which is an obvious way to relate it to the psychoticism found in our work.

In contrast to convergent thinking, which generally leads to conventional and correct solutions, divergent thinking, characteristic of high psychoticism, is defined as the process of generating many alternative ideas (Williams et al., 2016) and occurs in a universe that does not initially recognize boundaries or exclusions. This notion has become key to the mechanism underlying creativity; it exemplifies how the creative brain acts cognitively and is a variable that can be quantified. Divergence means considering different perspectives, looking for more than one answer, dismantling rigid schemes, and not relying on single, prior assumptions, "that is, trying out, making new associations, selecting in unusual ways, restructuring the apparently unusual or useless, going down unexpected paths, and testing to produce something new or unknown" (Torrance and Myers, 1976, p. 11).

It is clear that the pragmatism and instrumental aggressiveness found in subjects with higher psychoticism endow these basketball players with a better "sixth sense," a term used in sports to refer to the early discovery of tactical signals after the training received. This explains why TPT has a significant impact on athletes with higher psychoticism, similar to its impact on intelligence. As García Peñas et al. (2021) state, sport constitutes "a very favorable context for innovation, as it usually entails a persevering task of improving the skills that come into play." Other authors emphasize the innovative attitude that a high-performance athlete must have (Hackfort and Schinke, 2020), and at the core of such an attitude is the creativity of the subject with a propensity for psychoticism. Memmert (2015) defines it as "unusual, innovative, statistically rare, or even unique behavior in solutions to a sport-related situation".

This unusual and innovative attitude makes the basketball player with high psychoticism a greater beneficiary of TPT, even though it also benefits others. As Williams et al. (2016) assert, the convergent thinking of low-psychoticism subjects leads to conventional and "correct" solutions, while the divergent thinking of high-psychoticism basketball players generates many "alternative ideas," allowing them to take better advantage of the TPT designed for this research.

This finding can become a resource to develop creativity, which is crucial for good tactical performance. It can find through TPT a way to stimulate the brain from a cognitive point of view, allowing for a quantitative approach complemented with qualitative assessments observed by experts during real basketball games. The present research can enrich the understanding of the relationships between intelligence and creativity to assimilate perceptual tactical training, increase performance, and facilitate criteria for selecting athletes with certain personality characteristics to enhance creativity in ball game sports.

Sport psychology needs to explore and scientifically substantiate observations such as these, and it is not possible to do so solely with descriptive studies, translations, psychometric adaptations, and mass applications, but with correct and accurate explorations of variables, as close as possible to the specific sport activity.

5 Limitations and future research

The limitations encountered and future research that could be undertaken can be summarised as follows:

1 **Sample size limitation:** The size of the sample restricts the generalizability of findings to basketball players of different ages and backgrounds.
2 **Inclusion of psychophysiological evaluations:** Future studies could incorporate psychophysiological evaluations such as heart

rate monitoring, skin conductance, thermometry, and other relevant measures. These could provide insights into physiological responses during perceptual tactical training sessions.

3 **Utilization of advanced information technologies:** Leveraging advancements in information technology, future research could explore the use of moving images. This approach could enhance the complexity of tactical scenarios presented, thereby enriching the perceptual training experience.

These considerations aim to address current limitations and propose avenues for further enhancing the effectiveness and scope of perceptual tactical training in basketball.

6 Conclusion

Abstract reasoning ability and a predisposition toward psychoticism play a key role in enhancing tactical perception through perceptual tactical training (PTT).

Players with higher abstract reasoning ability demonstrated greater accuracy in perceiving tactical situations, highlighting the importance of analogical reasoning in identifying game dynamics. However, this ability alone does not guarantee the generation of optimal tactical solutions, emphasizing the need to complement intelligence with practical knowledge and experience.

Although the PTT improved participants' perception abilities, it was not sufficient to directly enhance the accuracy of tactical solutions. This suggests that tactical decision-making requires a multifaceted approach that combines intelligence, experience, and deliberate practice.

The results also suggest that psychoticism, combined with abstract reasoning, facilitates the rapid identification of critical aspects in tactical situations, which can be beneficial for decision-making in basketball.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Faculty of Psychology, University Seville, Spain. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

CD-R: Writing – original draft, Writing – review & editing. EP-C: Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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María Teresa Anguera Argilaga: pioneer of observational methodology and an example of wisdom and humanity

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María Teresa Anguera Argilaga, professor emeritus at the University of Barcelona, dedicated her life to developing observational methodology in behavioral sciences and to humbly and generously training those who knew her. Her legacy leaves a deep mark on education, psychology, and social sciences.

At a time when Spanish psychology was asserting its scientific identity, Dr. Anguera built a solid multidisciplinary foundation by studying teaching, philosophy (with a specialization in psychology), and law, thus enriching her scientific vision. She stood out for her methodological rigor, her keen analytical skills, and, fundamentally, for her human qualities and commitment to service.

A career of academic excellence and multidisciplinary application

Dr. Anguera's research focused on observational methodology and program evaluation design, leading numerous competitive projects and publishing in prestigious international journals. Her integrative approach to qualitative and quantitative methods made her a key figure in the development of *Mixed Methods*.

She was principal investigator on multiple initiatives and coordinated the Research and Innovation in Designs Group (GRID), promoting the application of multimedia and digital technologies in research. Her contributions, such as the innovative HOISAN software, made it possible to code and analyze behavior with unprecedented accuracy. These tools have facilitated the study of social and behavioral dynamics in classrooms and sports environments.

Her work has been especially valuable in providing practical methods for understanding and evaluating human interactions. Her ability to connect theory and practice inspired generations of professionals to approach their disciplines with scientific rigor and human sensitivity.

Exceptional teacher, inspiring mentor, and model of humility

In her teaching role as professor in the Department of Behavioral Science Methodology at the University of Barcelona, Dr. Anguera taught at all educational levels. Her commitment to education transcended the classroom, actively participating in doctoral and master's programs at universities in Spain and Portugal, always with a clear, rigorous, and approachable teaching style.

However, what truly distinguished Dr. Anguera was her profound humility and generous willingness to help others. Despite her many achievements, she always remained accessible and altruistic. Students and colleagues remember her dedication to guiding those who sought her advice, both academically and personally. Her professional ethics and human warmth made her an exemplary role model, both in the academic and personal spheres.

For her students, she was a constant source of inspiration, teaching them that academic excellence must be inseparably linked to empathy and social commitment, fundamental values for those dedicated to educating others.

Well-deserved recognition and an indelible legacy

Her outstanding career was recognized with honorary doctorates from universities such as La Laguna, Las Palmas de Gran Canaria, Pontificia de Salamanca, and Lérida. However, her greatest legacy lies in the transformative impact of her work and the example she set for us: the harmonious combination of academic excellence, deep empathy, and dedication to service.

Dr. Anguera's passing left an irreplaceable void in the Spanish Academy of Psychology (of which she was a member) and in the university, but also an indelible legacy. Her smile, her kindness, and her constant willingness to help live on in the memory of those who knew her. Her influence transcended research methodology; she transformed the understanding of science and the meaning of serving others. She was a teacher of methodology and, even more, a teacher of life, demonstrating that professional success and humility not only can but must coexist.

For future professionals and researchers, her life remains a timeless testament to the idea that excellence is not defined solely by academic accolades, but by the ability to inspire and elevate others. Her legacy lives on through the countless applications of Observational Methodology and the classrooms shaped by her pedagogical influence. She revolutionized the way we teach, investigate, and understand science with precision and humanity.

Beyond her scholarly legacy, Dr. Anguera embodied the rare blend of intellectual rigor and human warmth. Her journey reminds us that true success lies in cultivating both professional excellence and an unwavering commitment to the service of others—with empathy, humility, and gratitude.

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