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Towards a psychophysiological approach in physical activity, exercise, and sports, volume III

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Towards a psychophysiological approach in physical activity, exercise, and sports, volume III

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Editorial: Towards a psychophysiological approach in physical activity, exercise, and sports, volume III

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KEYWORDS

sports, psychology, behavior, physiology, load

Editorial on the Research Topic
Towards a psychophysiological approach in physical activity, exercise, and sports, volume III

"*Towards a psychophysiological approach in physical activity, exercise, and sports-volume III*" explores the complex interactions between physical activity, exercise, and psychological factors in various populations and analytical contexts. A recurring theme across studies is the emphasis on how psychological factors, such as anxiety, self-confidence, and attentional control, interact with physiological outcomes like heart rate variability (HRV) and perceived exertion. Key findings include the enhancement of performance through strategic psychological interventions (e.g., mindfulness, positive thinking) and the understanding that physical activity can alleviate mental health symptoms, especially in populations with chronic conditions such as long COVID. The studies also collectively underscore the importance of a holistic approach to optimizing performance in individual and team sports, where psychological wellbeing plays a crucial role in optimizing physical outcomes. Hoffmann et al. investigated the effects of hypnosis on elite Downhill Mountain bikers. The study found that hypnosis helps athletes reduce anxiety, improve self-confidence, and enhance performance and HRV. Breido et al. developed the Sport Preference Questionnaire (SPOQ) to assess the psychological effects of physical activity in children with mental illness. Results showed that different psychiatric conditions influenced physical activity levels and perceptions of fitness. Wu et al. explored RPE-derived metrics for predicting injury risk in curlers and found that the Exponentially Weighted Moving Average (EWMA) metric without delay is the most accurate variable. Moura et al. examined the relationship between psychological factors and performance in long and triple jumpers, finding that emotion regulation and self-control were key to better performance. A study by Liu et al. highlighted the impact of expressive ties on competitive performance using Dance Sport dyads, showing that emotional intelligence (EI) influences performance through athlete engagement. Wang et al. investigated the relationship between coaching behavior, team cohesion, and competitive anxiety in handball, suggesting that fostering cohesion and promoting task-oriented goals can alleviate anxiety. Qi and Jinmin used Mendelian randomization to show that cognitive performance mediates the relationship between education and physical activity. Schittenhelm et al. compared slow- vs. fast-beat music during rowing, finding that while fast music improved performance, slower-tempo music is adequate for recovery. Grønset et al. examined how mental processes like arousal regulation and mental toughness affect performance in football and found that mental toughness plays a critical role in overcoming challenges. Shi et al. found that mindfulness training improved attentional control during football penalty shootouts, highlighting its potential to reduce anxiety and enhance performance. Ferreira et al. assessed Project SCORE in promoting Positive Youth Development, showing improvements in athletes' life skills. Teixeira et al. used machine learning to predict recovery states in youth football players, achieving high classification accuracy. Yu et al. reviewed exercise interventions for maternal depression, anxiety, and fatigue, showing that yoga and Pilates were most effective for specific symptoms. A study by Gao et al. on sport and personality in adolescents showed that different activities influenced traits like openness and conscientiousness, with significant differences between genders. Rawls and Finomore examined attentional focus during perceptual tasks, finding that external focus reduces internal workload and stress. Sirotiak et al. investigated the impact of physical activity on health in individuals with long COVID and found that higher levels of physical activity improved perceived health outcomes. Sim et al. studied sport anxiety and life satisfaction in male athletes, noting that positive thinking skills moderate the relationship between anxiety and satisfaction. Tolukan et al. analyzed error perception in athletes with disabilities, highlighting the role of reflection and challenge in deliberate practice.

The main conclusions drawn from these studies highlight the critical role of psychological factors in enhancing physical performance, particularly in the context of sports and physical activity. Interventions aimed at improving psychological resilience, such as mindfulness, positive thinking, and anxiety management, have been shown to be effective in boosting athletes' performance and overall wellbeing. In the context of physical activity, exercise, and sport prescribing, these findings suggest that incorporating psychological training into exercise regimens can be highly beneficial, particularly for athletes facing high levels of stress or chronic health conditions. A deeper understanding of the dynamic interaction between the mind and body will be possible through the incorporation of these technologies into research approaches. Research is using neuroimaging to map patterns of brain activity linked to motivation, focus, judgement, and maximizing performance. In the coming years, researchers will investigate novel psychophysiological interventions aimed at enhancing performance and boosting health in a variety of populations, building on current knowledge. All of these assumptions have been and will continue to be areas of interest to explore for a psychophysiological approach to physical activity, exercise and sport.

Author contributions

PF: Writing – review & editing. JT: Writing – original draft. DP: Writing – review & editing. DM: Writing – review & editing.

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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Sports preferences in children and adolescents in psychiatric care—evaluation of a new questionnaire

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Introduction: As part of an exploratory and hypothesis-generating study, we developed the Sports Preference Questionnaire (SPOQ) to survey the athletic behavior of mentally ill children and adolescents, subjectively assessed physical fitness and perceived psychological effects of physical activity.
Methods: In a department of child and adolescent psychiatry, we classified 313 patients (6–18 years) according to their primary psychiatric diagnosis. The patients or—in the parental version of the questionnaire—their parents reported their sport preferences on the SPOQ. As possibly influential factors, we also assessed the frequency of physical activity, the importance of a trainer, coping with everyday life through physical activity, and subjectively perceived physical fitness.
Results: One in 3 patients (32.4%) stated that they were not physically active. Patients diagnosed with eating disorders reported, on average, a notably high frequency (median of 3 h/week) and degree of coping with daily life through physical activity (median of 5 on a 6-point Likert scale). Patients with anxiety disorders and depression had the lowest self-perception of physical fitness (mean value of 3.1 or 3.7 on an interval scala from 0 to 9). The presence of a trainer was generally considered not important, except for ADHD patients (median of 3 on a 6-point Likert scale).
Conclusion: The SPOQ is sensitive for differential effects of core child and adolescent disorders as well as for main covariates influencing the complex association between physical activity and emotional and behavioral disorders in children and adolescents. Based on this pilot study, we discussed the need for an efficacy study to measure the effects of sports therapy.

KEYWORDS
Sports Preference Questionnaire, mental disorder, sports therapy, psychological effect, physical activity

Abbreviations
ADHD, attention deficit hyperactivity disorder; DEPR, depression; ED, eating disorder; e.g., exempli gratia; et al., et alia; i.e., id est; OCD, obsessive compulsive disorder; ODD, oppositional defiant disorder; OMD, other mental disorders; P/AD, phobia/anxiety disorders; S/AD, stress/adjustment disorder; SPOQ, Sports Preference Questionnaire.

Key practitioner message

- One in 3 patients not physically active
- High coping with daily life through physical activity in eating disorder patients
- Lowest self-perception of physical fitness in patients with anxiety disorders
- The presence of a trainer most important in ADHD patients

1 Introduction

The positive effect of physical activity on general health is well known and has already been proven in numerous studies. For example, reduced risk of cardiovascular disease, stroke, and cancer as well as improved stress regulation through regular exercise have been shown (1, 2).

Physical activity is also a very effective and suitable means of preventing mental illness and improving mental health [e.g., (3–6)]. When investigating the psychological effects of physical activity, positive effects on mood, psychological well-being and the concept of self and body could be demonstrated (4, 7). The effect of exercise has also been investigated at the neurobiological level. Changes in the metabolism of serotonin and dopamine in the brain have been demonstrated (8). These messenger substances play a decisive role in the development and maintenance of many mental illnesses such as depression, anxiety disorder, and attention deficit hyperactivity disorder (9–11).

Under the right conditions in organized sports, children and adolescents may develop daily life-skills such as moral reasoning, emotional control, personal responsibility, and the ability to work in teams and set goals (12). In the literature, there are a few specific sports therapeutic approaches for mentally ill children and adolescents, for example in the areas of climbing therapy, archery, and endurance training (13–16). A German study with ADHD patients showed that both long-term, natural sports therapy, and high-intensity interval training (HIT) tend to have a positive influence on the main symptoms, self-esteem and social competence (17). Nevertheless, there are only a few confirmatory studies on the content, methodology, and structure of sports therapies that do not allow generalized statements on the effects and mechanisms of action in mentally ill children and adolescents (18).

While the effects of physical activity on health have been well researched, it still seems to be largely unclear what psychological conditions need to be in place for effective sports intervention in mentally ill children and adolescents. According to Lambert (19), a healthy therapeutic relationship is a helpful factor in psychotherapy. Because a skilled coach also performs therapeutic functions in sports therapy, he could play a similar role. The desire for enjoyment in physical activity appears to be the best predictor of commitment (20). As a result, the sports treatment provided should be as appropriate as feasible, according to the individual's demands and preferences. However, a relationship between the incidence of eating disorders and aesthetic sports such as ballet or gymnastics, but also athletics should be explored (21, 22). Psychotherapy research has shown that resource-activating strategies achieve higher therapeutic success (23). This finding could be integrated into sports therapy by focusing on the patients' athletic abilities and personal goals. Kirkaldy et al. (5), also point out that more positive feedback regarding physical activity and social recognition leads to a better self-image. This seems to be of particular importance, as people with mental disorders often feel, that they have insufficient athletic self-efficacy (24). In the long term, sports therapy according to the above-mentioned aspects, could be a good way to achieve regular exercise and thus an improvement in physical fitness and mental health, even beyond the therapeutic intervention.

However, there are almost no scientific findings on the athletic behavior of mentally ill children or adolescents and the successful implementation of sports therapy in child and adolescent psychiatry. Therefore, the aim of the present study is to explore basic findings as a first step of evidence-based sports therapy in the child and adolescent psychiatric setting. To collect new data in our clinic, existing questionnaires on athletic behavior were considered, e.g., the ATPAD scale (25), AMS-Sport (26), and EMI-2 (27). Another very detailed questionnaire for sports interests asks about sports, sports games, and orientation (28). However, no questionnaire was found that captures physical activity preferences considering the aspects of self-perception, resource activation, and problem-solving in the context of a structured sports therapy history. Consequently, the Sport Preference Questionnaire (SPOQ) was designed. The SPOQ aims to investigate the athletic behavior of mentally ill children and adolescents, assess physical fitness and perceived psychological impacts of physical activity, and develop both general and disorder-specific hypotheses.

2 Material and methods

2.1 SPOQ questionnaire

The SPOQ was created in 2015 by the authors to investigate the out-of-school athletic behavior of children and adolescents aged six to 18. The item pool includes questions based on psychotherapy criteria such as therapeutic connection, resource activation, and problem-solving (29). We expected that physical activity with more of these features would be more useful for mental health. The item pool was constructed by a team of sports scientists, psychiatrists, and psychotherapists, taking into account the literature stated in the introduction. Two versions were designed, the parental and the self-report version (from ten years old). The data were collected with the German versions of the questionnaire. Both German versions were translated into English by a bilingual American and were translated back by a bilingual German. In the first version, thirty-nine percent of the questions regarding the importance of the relationship with the trainer and daily coping through physical activity were left unanswered. These patients were returned their unfilled SPOQ one day after submission to complete the missing data. Most patients indicated that they had overlooked the questions, which is why the layout was optimized after 2 months of data collection.

The SPOQ consists of five sections (see attachment). The first section records the frequency of physical activity in the last six months in hours per week. There is also a free field to write down another frequency. Besides, there is a statement that can be marked with a cross, indicating that the respondent has never been physically active.

The second section records up to three types of physical activity that have been regularly exercised at least in the last six months. Also, the location where the physical activity is performed is recorded. There are three answer options possible: Sports Club, Gym and Other. On a Likert scale from "Not at all" (1) to "Very much" (6), participants specify their enjoyment of this type of activity. The numbers 2–5 on the Likert scale are without description.

The third section is designed as 2 statements and asks for a currently important relationship with at least 1 trainer and the current daily coping through physical activity. Again, answers are recorded using a Likert scale from 1 to 6.

The fourth section records up to five types of activity ever tried during the participant's lifetime. Also, the duration, expressed in months, is recorded. The enjoyment of types of activities is measured as in the second section.

Section Five asks for the subjective assessment of the physical fitness of the 163 patients to measure their athletic self-efficacy. This assessment is done via an interval scale from "Not physically fit" (0) to "Very physically fit" (9). The numbers 2–8 are without description.

It takes about 5 min to complete the SPOQ. The parental and self-report versions of the SPOQ can be used for free disposal. The German versions can be requested from authors.

2.2 Mental disorders

The type of mental disorder was diagnosed by trained clinical psychologists or psychiatrists according to ICD-10 (30), subject to the regulations. For this purpose, semi-structured clinical interviews were used in line with Sheehan et al. (31). The diagnoses were confirmed with disorder-specific questionnaires if this was necessary to complete the symptom profiles.

2.3 Participation

From October 2015 to October 2017, questionnaires were send to 450 patients, of whom were registered as an inpatients or outpatients at the Child and Adolescent Psychiatry from the ages of 6.0–18.0 years. One hundred and sixty-eight inpatients received the self-report SPOQ, while 282 parents of outpatients received the parental version as part of the general registration process. It was explicitly ensured that only 1 SPOQ was available for each patient. Since the questionnaire was obligatory for inpatients, all 168 questionnaires were received back from the self-report. Two inpatients without a diagnosed disorder were excluded. One hundred and thirty-five questionnaires from the parental version were excluded because of no return or no diagnosed mental disorder. All included questionnaires covered a total of 313 patients with a mental disorder in the evaluation, 166 inpatients (self-report), and 147 outpatients (parental version). The concrete division and response rate are clearly shown in a flow chart (Figure 1).

2.4 Data collection and analysis

Data were collected and managed using REDCap research electronic data capture tools (32). Since the study design was strictly exploratory, we did not use inference statistics but kept analyses on a descriptive level. The statistics were calculated with R 3.6.2 (33). The flowchart to report patient selection, Figure 1, was made using the package "DiagrammeR" (34). Boxplots, line plots, and the heatmaps to show sports preferences in boys and girls were generated with the package "ggplot2" (35).

Boxplots, Figures 2–6, were generated by diagnosis group and type of questionnaire for the frequency of physical activity, enjoyment of physical activity (related to the first-mentioned physical activity), the importance of a trainer, daily coping through physical activity, and subjectively perceived physical fitness. Therefore, N counts for the number of considered cases and NA for the number of missing values. Two line plots, Figures 7, 8, were generated to show the mean of subjectively perceived physical fitness by age, respectively frequency of physical activity, separated for gender and type of questionnaire. Six patients reported more than 10 h of physical activity per week in the self-report questionnaire. We assumed that corresponding patients were not able to estimate the actual time. Therefore, the following data were considered missing. To present the first-mentioned type of physical activity for girls, and boys heatmaps, Figures 9, 10, were created. Therefore, the mentioned types of physical activity were later aggregated into six branches by the authors. The weight, the percentage of the mentioned type in the corresponding diagnosis group, was shown through gray gradation. Table 1 shows the main characteristics of the data.

An ethics vote with the number 837.515.15 (10833) from the ethics review board of the Landesärztekammer Rheinland-Pfalz exists for this study. Following the advice of the ethics review board, we did not assess individual informed consent statements since the procedure was fully integrated in our clinical routine assessment.

3 Results

3.1 Patients

A total number of 313 patients could be taken into account. They could be grouped into eight diagnostic categories according to the predominant mental disorder: Depression (DEPR) $N = 72$, median age = 15.1, eating disorders (ED) $N = 24$,

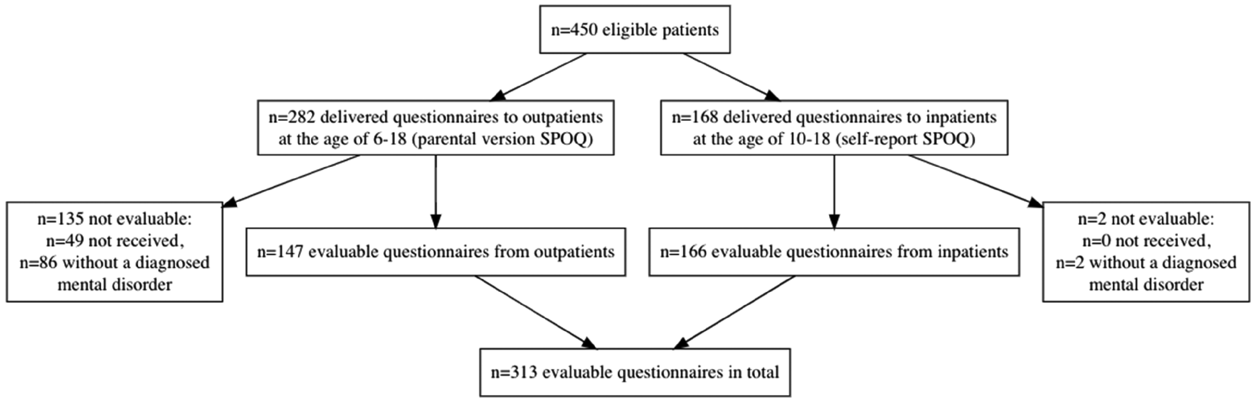

FIGURE 1
Report on patient selection.

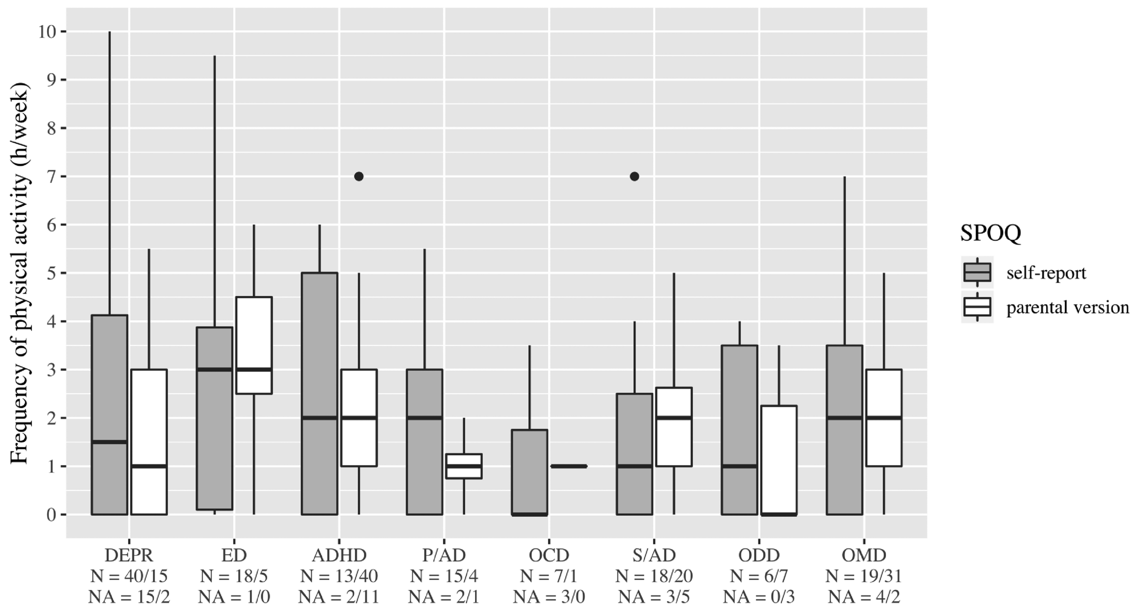

FIGURE 2
Frequency of physical activity. DEPR, depression; ED, eating disorder; ADHD, attention deficit hyperactivity disorder; P/AD, phobia/Anxiety disorder; OCD, obsessive compulsive disorder; S/AD, stress/adjustment disorder; ODD, oppositional defiant disorder; OMD, other mental disorders.

median age = 15.6, attention deficit hyperactivity disorder (ADHD) *N* = 66, median age = 10.4, phobia/anxiety disorders (P/AD) *n* = 22, median age = 15.7, obsessive compulsive disorder (OCD) *n* = 11, median age = 16.1, stress/adjustment disorder (S/AD) *n* = 46, median age = 12.3, oppositional defiant disorder (ODD) *n* = 16, median age = 13 and other mental disorders (OMD) *n* = 56, median age = 11.9. Diagnostic group assignment was done by the primary psychiatric diagnosis on the first axis of the multi-axial diagnostic system (ICD-10) irrespectively from comorbidities.

In the inpatient group (self-report), DEPR was the predominant disorder, accounting for 33% of cases. The median age was 15.1 years, and 58% were female. In the outpatient group (parental version), ADHD was the leading disorder with 35% of the cases. The median age was 10.6 years, and 66% were male.

The complete main characteristics, overall and subdivided by questionnaire type, can be found in Table 1.

3.2 Athletic behavior

On average, patients with ED stated a higher frequency of physical activity than the other diagnosis groups (Figure 2). In all diagnostic groups, high enjoyment of physical activity was

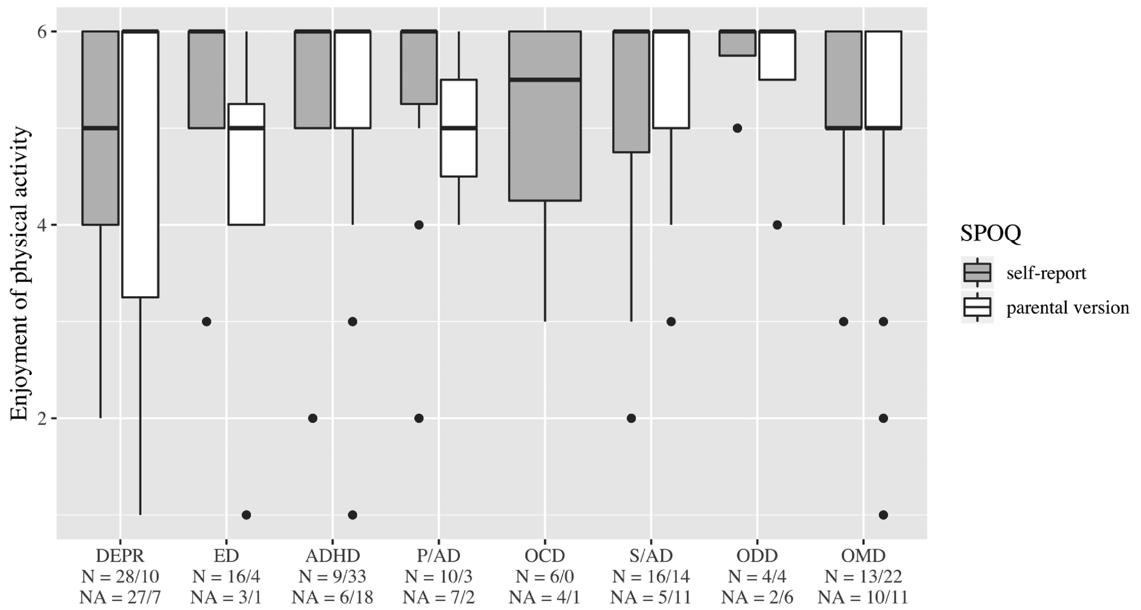

FIGURE 3
Enjoyment of physical activity (related to the first mentioned physical activity. DEPR, depression; ED, eating disorder; ADHD, attention deficit hyperactivity disorder; P/AD, phobia/anxiety disorder; OCD, obsessive compulsive disorder; S/AD, stress/adjustment disorder; ODD, oppositional defiant disorder; OMD, other mental disorders.

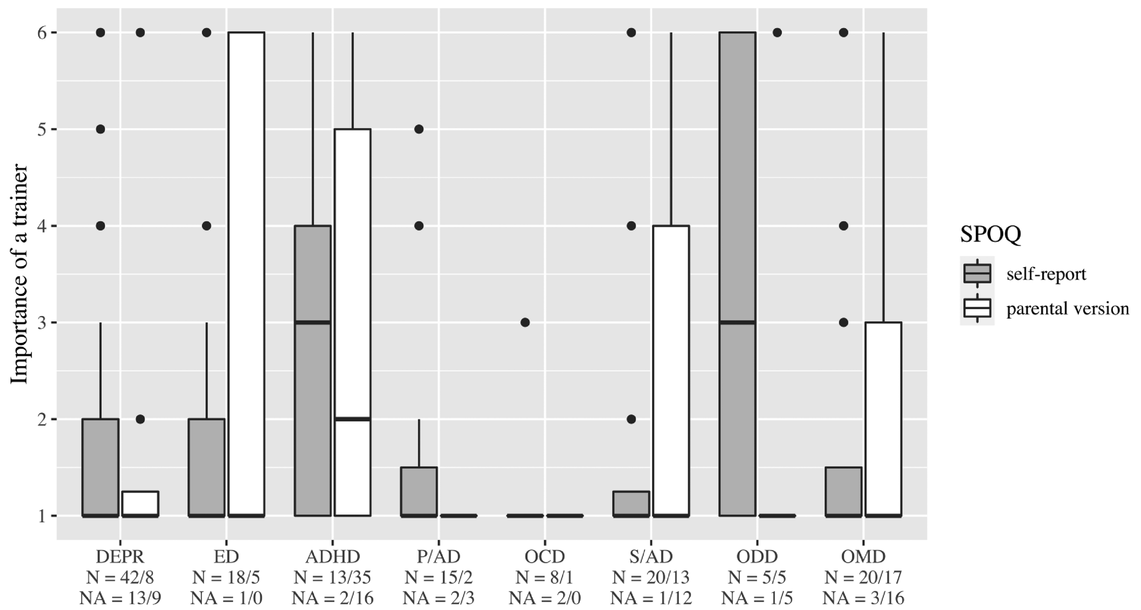

FIGURE 4
Importance of a trainer. DEPR, depression; ED, eating disorder; ADHD, attention deficit hyperactivity disorder; P/AD, phobia/anxiety disorder; OCD, obsessive compulsive disorder; S/AD, stress/adjustment disorder; ODD, oppositional defiant disorder; OMD, other mental disorders.

reported with medians between 5 and 6, however, with a wide variety in the group of patients with DEPR (Figure 3). The importance of a trainer was rated very low with a median of 1 in almost all groups. Only patients with ADHD and ODD and parents of children with ADHD rated it higher at the median (Figure 4). In the assessment of daily coping through physical activity, there was a wide range. In the self-report, patients with ED and OCD gave the highest scores and patients with DEPR and P/AD the lowest scores, on average (Figure 5). There is a discrepancy between self-report and parental version regarding subjectively perceived physical fitness. In the external assessment, higher values were indicated, on average. Physical fitness was

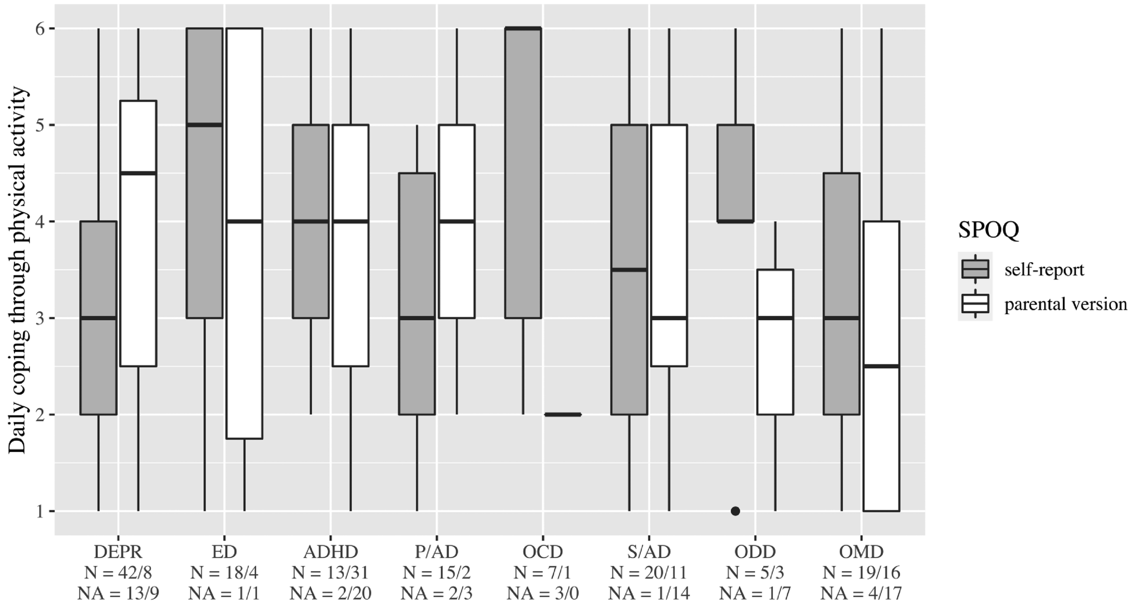

FIGURE 5
Daily coping through physical activity. DEPR, depression; ED, eating disorder; ADHD, attention deficit hyperactivity disorder; P/AD, phobia/anxiety disorder; OCD, obsessive compulsive disorder; S/AD, stress/adjustment disorder; ODD, oppositional defiant disorder; OMD, other mental disorders.

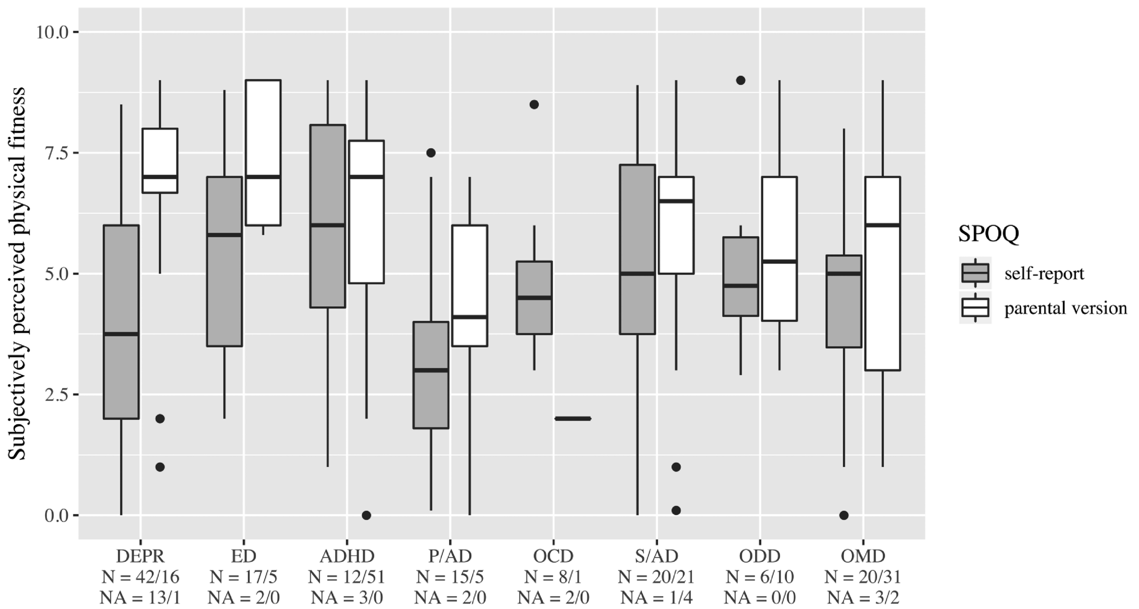

FIGURE 6
Subjectively perceived physical fitness. DEPR, depression; ED, eating disorder; ADHD, attention deficit hyperactivity disorder; P/AD, phobia/anxiety disorder; OCD, obsessive compulsive disorder; S/AD, stress/adjustment disorder; ODD, oppositional defiant disorder; OMD, other mental disorders.

rated particularly low in the self-assessment of patients with DEPR and P/AD (Figure 6).

If we look at the mean values of subjectively perceived physical fitness as a function of age, the parental questionnaire for girls shows only minor deviations (mean values between 5.0 and 6.6). For boys, the mean value in the parental assessment varies similarly to the girls between 5.0 and 6.7, but with a dip at the age of 14 to 15 years (mean value 3.7). In self-perception, physical fitness at the age of 10–11 years is initially rated good on average by both genders (mean value 7.4 for girls and 6.3 for boys). However, at ages 12–13 for girls and 14–15 for boys, the mean drops sharply to 3.4 and 4.5, respectively (Figure 7). Let us now consider the

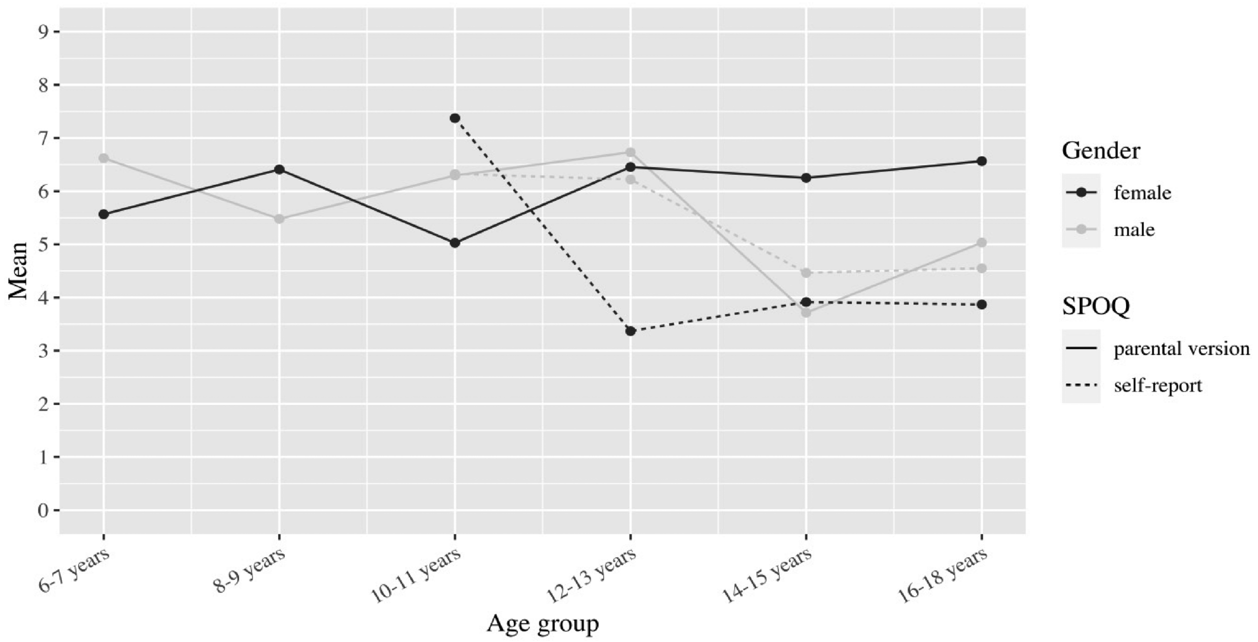

FIGURE 7
Subjectively perceived physical fitness by age and gender.

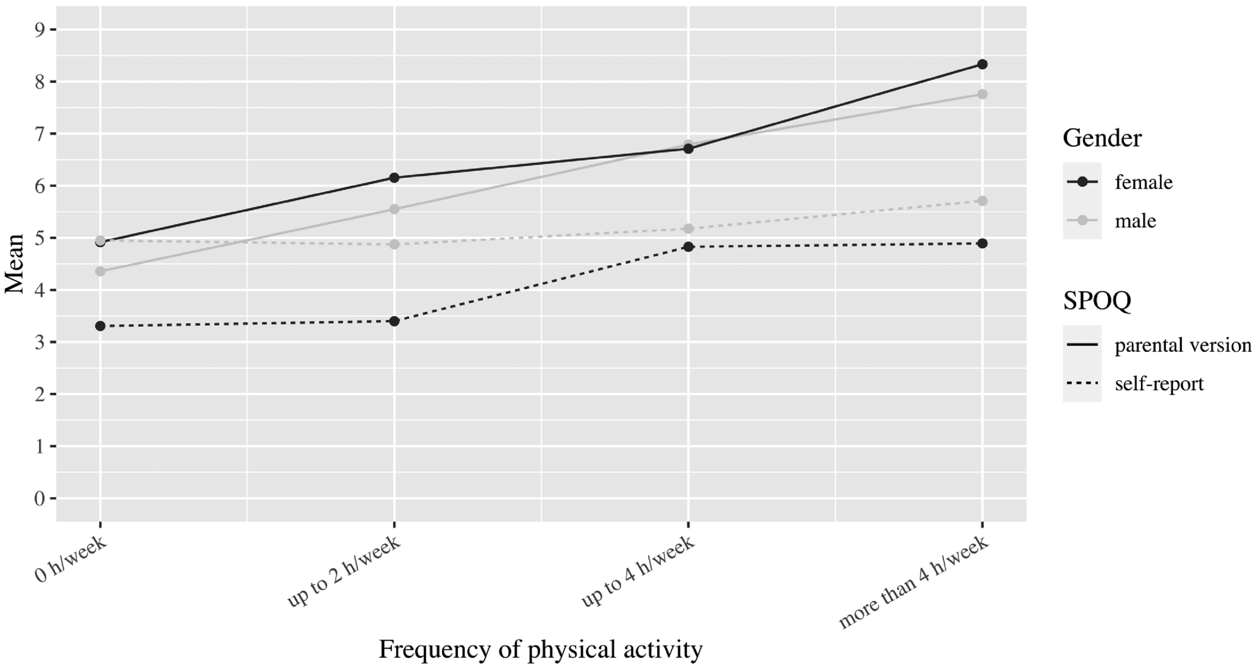

FIGURE 8
Subjectively perceived physical fitness by frequency of physical activity and gender.

dependence of subjectively perceived physical fitness on the frequency of physical activity. In the parent ratings, the average perception of fitness increases steadily with frequency for both genders (from 4.4 to 7.8 for boys and 4.9 to 8.3 for girls). However, gender differences are evident in self-perceptions. While girls' perceived fitness also increases on average with frequency (from 3.3 to 4.9), there seems to be no clear relationship for boys. With no or little physical activity, they rate their fitness on average considerably better than

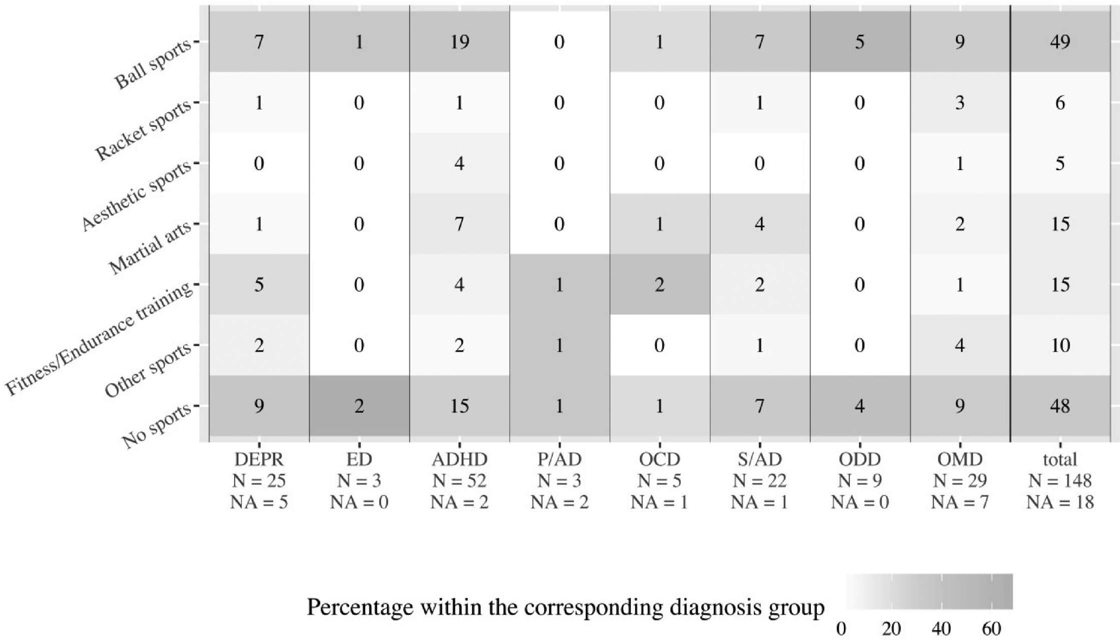

FIGURE 9
First-mentioned type of physical activity in boys. DEPR, depression; ED, eating disorder; ADHD, attention deficit hyperactivity disorder; P/AD, phobia/anxiety disorder; OCD, obsessive compulsive disorder; S/AD, stress/adjustment disorder; ODD, oppositional defiant disorder; OMD, other mental disorders; Ball sports means handball, soccer, basketball; Racket sports means table tennis, tennis, badminton; Aesthetic sports means dancing, gymnastics, vaulting; Martial arts means karate, judo, boxing; Fitness/Endurance training means gym, weight training, cycling, jogging; Other sports means swimming, climbing, athletics.

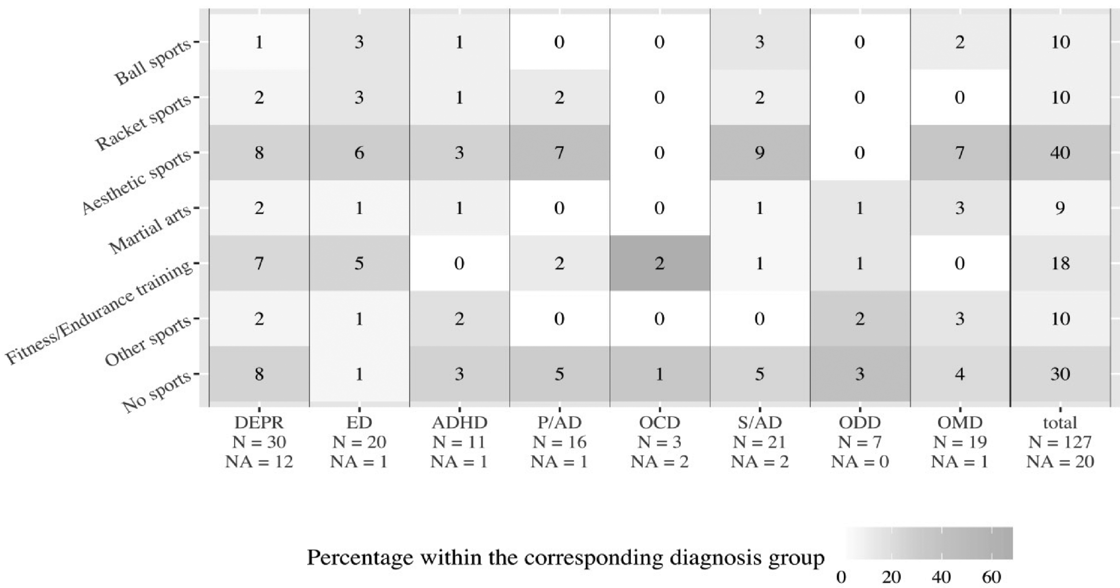

FIGURE 10
First-mentioned type of physical activity in girls. DEPR, depression; ED, eating disorder; ADHD, attention deficit hyperactivity disorder; P/AD, phobia/anxiety disorder; OCD, obsessive compulsive disorder; S/AD, stress/adjustment disorder; ODD, oppositional defiant disorder; OMD, other mental disorders; Ball sports means handball, soccer, basketball; Racket sports means table tennis, tennis, badminton; Aesthetic sports means dancing, gymnastics, vaulting; Martial arts means karate, judo, boxing; Fitness/Endurance training means gym, weight training, cycling, jogging; Other sports means swimming, climbing, athletics.

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TABLE 1 Table of characteristics.

Diagnosis group	Total number (%)	Median age, years (range)	Male (%)/female (%)
All			
Total	313 (100)	13.8 (6.1, 18)	166 (53)/147 (47)
DEPR	72 (23)	15.1 (10, 18)	30 (42)/42 (58)
ED	24 (8)	15.6 (11.2, 18)	3 (12)/21 (88)
ADHD	66 (21)	10.4 (6.2, 16.7)	54 (82)/12 (18)
P/AD	22 (7)	15.7 (11.8, 17.8)	5 (23)/17 (77)
OCD	11 (4)	16.1 (13.2, 17.4)	6 (55)/5 (45)
S/AD	46 (15)	12.3 (6.1, 18)	23 (50)/23 (50)
ODD	16 (5)	13 (6.8, 16.6)	9 (56)/7 (44)
OMD	56 (18)	11.9 (6.1, 17.9)	36 (64)/20 (36)
Self-report			
Total	166 (100)	15.1 (10.8, 18)	69 (42)/97 (58)
DEPR	55 (33)	15 (12.2, 18)	20 (36)/35 (64)
ED	19 (11)	15.6 (13.2, 18)	1 (5)/18 (95)
ADHD	15 (9)	14 (11.5, 16.2)	15 (100)/0 (0)
P/AD	17 (10)	16.3 (11.8, 17.8)	4 (24)/13 (76)
OCD	10 (6)	15.9 (13.2, 17.4)	5 (50)/5 (50)
S/AD	21 (13)	14.9 (10.8, 17.4)	7 (33)/14 (67)
ODD	6 (4)	13.1 (10.9, 16.6)	2 (33)/4 (67)
OMD	23 (14)	14.1 (11.1, 17.9)	15 (65)/8 (35)
Parental version			
Total	147 (100)	10.6 (6.1, 18)	97 (66)/50 (34)
DEPR	17 (12)	15.2 (10, 17.4)	10 (59)/7 (41)
ED	5 (3)	15.9 (11.2, 17.8)	2 (40)/3 (60)
ADHD	51 (35)	9.2 (6.2, 16.7)	39 (76)/12 (24)
P/AD	5 (3)	14.2 (12.3, 16.8)	1 (20)/4 (80)
OCD	1 (1)	16.2 (16.2, 16.2)	1 (100)/0 (0)
S/AD	25 (17)	10.9 (6.1, 18)	16 (64)/9 (36)
ODD	10 (7)	11.2 (6.8, 15)	7 (70)/3 (30)
OMD	33 (22)	9.1 (6.1, 17.6)	21 (64)/12 (36)

girls (mean 5.0 for boys vs. 3.3 for girls in the no physical activity group). Compared to the parental assessment, the self-assessment is generally worse, except for the assessment of the boys in the group without physical activity (Figure 8).

The heatmaps revealed that 33% of male patients were tied to ball sports, while 32% of all male patients did not participate in sports (Figure 9). Among female patients, 32% were tied to aesthetic sports, while 24% of all female patients did not participate in sports (Figure 10).

3.3 Feasibility

The return of the self-report SPOQ was 100% due to the treatment obligation for inpatients. The individuals needed between five and ten minutes for form completion. The parental-version was an addition to the registration form. The first section was missing 35% of the information, the second section 33%, the third section 54%, the fourth section 37%, and the last section was missing only 6%. We concluded that after completing the 12-page registration form, parents most likely did not want to engage in the specific topic of physical activity. The fewest missing items were in the last section, as this was probably the quickest to answer and, as the last question, had a higher visual focus.

4 Discussion

In our study, we capture an overview of the athletic behavior of mentally ill children and adolescents, subjectively assessed physical fitness, and perceived psychological effects of physical activity. One out of 3 patients reported not being physically active at all. Self-reported physical fitness in general declined with age and was perceived to be worst by patients with P/AD and DEPR. Patients with ED reported in particular high frequencies of physical activity and reported to use physical activity as an important resource to cope with their daily lives. The presence of a trainer was generally not considered to be unimportant, except for ADHD patients.

In line with a survey of a mentally healthy sample (118 girls and 127 boys) aesthetic sports for girls and sports games for boys were mentioned as preferred physical activities (36). In our sample 41% of all physically active female patients indicated aesthetic sports, and 55% of all physically active male patients said ball and racket sports were their first sport (Figures 9, 10). Swimming, which was cited in the study of Frömel et al. (36) was cited only occasionally as a preferred sport. Therefore, non-clinical samples may be also usefull to determine which kind of sports may be preferential to support in a clinical sample.

This may also be considered in developing resource-based sports therapy programs. But in particular, the knowledge of sports preference will be helpful to find an optimal sports fit in an expected third of patients who have not been physically active so far.

As expected clinically, individuals with P/AD and DEPR reported also in studies higher scores on negative self-concept as compared with the norm (37–39). This effect could be also seen in our study concerning physical activity (Figure 6).

With respect to gender, self-report (see also Figure 8) showed lower subjectively perceived physical fitness in girls regardless of frequency. There are several possible explanations for this finding. One line of explanation is the experience of negative feedback of peers during sport activity. This explanation is supported the survey of Slater & Tiggemann (40), in which 332 girls and 382 boys aged 12–16 were assessed. Both boys and girls reported being teased and discriminated in sports by same-sex peers. But only girls reported additionally being teased by opposite-sex peers (40). In sum, girl had a higher level of negative experience practicing sports, which can be drawn as one explanation of our finding on gender differences in sport self-image.

In consequence for practical issues regarding improvement of self-efficacy expectations and self-perception of personal strength, targeted interventions should be considered. As in most targeted interventions, this should be started in early ages, where our study in line with others found a higher level of willingness to practice sports. This may be particularly important if sports therapy is used for targeted intervention with patients suffering from P/AD and DEPR.

Since teasing has to be considered as an substantial negative factor for children and adolescents, which let them drop out of sports activity, mixed-gender groups should address non-teasing issues therapeutically right from the beginning.

It has to be highlighted that the subjectively perceived physical fitness follows different dynamics in girls and boys, which is very much in line with the average onset of puberty. While girls in our sample reported lower levels of physical fitness following the age range of 12–13 years, boys had a similar change of scores two years later (14–15 years of age).

Many adult patients with ED use physical activity to regulate negative affect and emotion as a coping strategy and develop a sports addiction (41–43). This deliberate use of physical activity as a coping strategy has been found in children and adolescents with ED (Figure 5) as well. It is highly recommended to pick up their habits and carry out sports therapy in addition to psychotherapy. The aim of combining sports therapy with psychotherapy must be to counter the risk of the development of a sports addiction. Monitored early sports activity can be handled much more effective by the therapist as oppose to self-administered sports without therapeutic framing, which may drive patients into sports addiction more easily.

As was reported in the literature, there was a strong proneness in patients with ED for physical activities related to weight control, such as aesthetic sports and athletics (55 percent, Figure 10) (21, 22). Translating this finding into therapeutic practice, besides starting sports therapy at a young age, the focus should be always set on fun and team-orientation. Sports with a high levels of self-control and weight management should be avoided or at least considered with caution.

Our data indicate that ADHD patients are more likely to value guidance from a trainer compared to other patients in the child and adolescent psychiatric context (Figure 4). They typically find it difficult to structure their actions due to their illness and need this from the outside (44, 45). While parents may lack the educational competence to be supportive in this aspect, children and adolescents receive clear structure, control, and action organization from professional coaches. As a result, they could prove to be more effective in achieving their goals in sports. To conclude, improving the relationship of children and adolescents should be a major focus of sports therapy treatment for children and adolescents with ADHD and may lead to symptom reduction.

4.1 Limitations

This study has several limitations: The study design is exploratory in nature. However, this is feasible for developing new instruments in new fields. Additionally, the SPOQ was cross-validated with the Strengths and Difficulties Questionnaire (SDQ) (46) and the EMI-2 (27), but not with other sport-specific instruments. Further, we did not formally test the questionnaire for reliability, which should be addressed in additional studies.

Inpatients and outpatients were not equally distributed between self-rating and parent rating, which limits the interpretation of the data since outpatients usually have lower scores on psychopathology as compared with inpatients. Nevertheless, the observed trend seem to be quite robust against the above mentioned confounding. Thus, the questionnaire evaluated in a population of 313 patients serves to generate hypotheses in an area with highly unmet research needs.

4.2 Implications and future directions

Only a few studies examine the athletic behavior of children and adolescents with mental disorders so far. A study with 1.2 million young adults showed that not exercising leads to a higher mental health burden (4). Our results revealed deficits in the frequency of physical activity per week. Almost 1 in 3 patients currently is not physically active (Figures 9, 10). Achieving an appropriate physical activity in children and adolescents should therefore be the primary task of sports therapy. The SPOQ is freely available for other institutions. The next step should be an efficacy study measuring the effects of a sports therapy program and testing hypotheses generated here.

Data availability statement

The datasets presented in this article are not readily available because the data cannot be made available to the public because of the confidentiality of the patient data. Requests to access the datasets should be directed to the data cannot be made available to the public because of the confidentiality of the patient data.

Ethics statement

The studies involving humans were approved by An ethics vote with the number 837.515.15 (10833) from the ethics review board of the Landesärztekammer Rheinland-Pfalz exists for this study. 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

FB: Investigation, Methodology, Writing – original draft, Writing – review & editing, Conceptualization, Data curation. SS: Investigation, Methodology, Writing – review & editing. EJ: Methodology, Writing – review & editing. MH: Writing – review & editing, Methodology.

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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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Starting in your mental pole position: hypnosis helps elite downhill Mountainbike athletes to reach their optimal racing mindset

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Introduction: Downhill Mountain Biking is an extreme sport requiring high mental strength to perform on the best level in a competition with only one run to win the race. The substantial challenge here is to control automatic processes like competitive anxiety and stress. Hypnosis can address these automatic processes. We developed and evaluated a hypnosis audio-intervention to activate the optimal racing mindset.

Methods: In our study, 19 elite Downhill Mountainbike athletes registered at two consecutive races of the IXS Downhill Cup. After the first race, athletes listened to the hypnosis audio-intervention. In this intervention, we instructed the athletes how to activate their optimal mental state before the second race. At both races, we measured competitive anxiety, stress, self-confidence, state resilience, and flow with validated questionnaires and assessed resting heart rate variability as physiological measure of resilience.

Results: Race-related somatic anxiety and subjective stress decreased significantly while self-confidence increased significantly from first to second race after athletes listened to the hypnosis. Heart rate variability was significantly increased at the second race indicating elevated vagal activity. When comparing race results of our participants to a control group of other elite athletes competing in the races but not listening to the hypnosis, we found that our study participants generally performed better in both races.

Conclusion: The study shows that our hypnosis intervention was effective in reducing competitive anxiety and stress while increasing perceived resilience and self-confidence: After a self-administered hypnosis session, athletes were able to improve automatic processes responsible for putting them in their mental pole position.

KEYWORDS
hypnosis, competitive anxiety, self-confidence, heart rate variability, Mountainbike downhill

Introduction

Downhill Mountain biking is a subdiscipline of mountain biking and a high-risk sport (Becker et al., 2013). Races are in an individual time-trial format, with cyclists starting at intervals. The aim is to complete a downhill race track in the fastest time possible on a defined route. Stress and anxiety levels are high on race day as athletes only get one single run to win the race. Tracks are physically and psychologically demanding including technical features, high speed sections and large jumps. A high level of self-confidence is one of the most important variables for Downhill Mountainbike speed (Chidley et al., 2015). Hence, not only physical fitness but mental strength is crucial for peak performance outcomes.

To achieve peak performance in a competition, athletes have to learn how to get into an optimal performance state (Privette, 1981; Ruiz et al., 2015). The "Individual Zone of Optimal Functioning" (IZOF) proposes an optimal performance state depending on athlete's personality, experience and the type of sport (Hanin, 2000). According to the Yerkes-Dodson law of an inverted U relationship between arousal and performance, low levels of arousal lead to boredom, while high levels of arousal cause anxiety, both resulting in deteriorated performance (Yerkes and Dodson, 1908). Therefore, we aim for an optimal level of arousal. Especially an increase of anxiety induces stress in the athlete and is associated with an elevated risk for injuries (Ivarsson et al., 2017). Finally, self-confidence increases with a growing ability to control arousal and anxiety (Liggett, 2004) and reveals a consistent relationship with performance (Craft et al., 2003).

Reaching peak performance is closely related to experiences of a flow state. The flow state is described as a positive psychological state of intense focus, concentration, control, and self-confidence. It typically occurs when an athlete's perceived skill matches the perceived challenges of a task (Nakamura and Csikszentmihalyi, 2009). A high level of self-confidence is associated with reaching flow state (Koehn, 2013). The experience of flow is crucial for competitive athletes as it facilitates the peak performance state (Koehn, 2013). A downhill Mountainbike descent provides an optimal setting for athletes to induce the core elements of flow (Taylor and Carr, 2021). One element of our intervention is thus the re-definition of the competition as an opportunity to feel great and again find back to the original motivation that made them choose their sport.

Many of the described experiences during flow state and optimal performance can also be experienced under hypnosis (Pates and Maynard, 2000). Hypnosis is a specific state of consciousness characterized by focused attention that increases the capacity to respond to suggestions (Elkins et al., 2015). Most hypnosis paradigms use specific suggestions to modify perception and behavior. Numerous studies have shown that a specific suggestion is associated with suggestion-specific neuronal, behavioral, and psychological effects (Schmidt et al., 2017; Franz et al., 2020; Franz et al., 2021; Schmidt et al., 2021). Therefore, a hypnotic trance depicts an effective way for athletes to reach their IZOF outside a competition (Meiss, 2016). A post-hypnotic trigger implemented during hypnosis and connected to the suggested feelings allows an automatic reactivation outside the hypnotic state. That means, participants experience the hypnosis session and all suggested feelings and then tie these feelings to an eliciting trigger that activates these feelings again outside of the hypnosis session. To illustrate this, participants can tie the feeling of safety to a piece of paper where they write the letter S for safety on it during hypnosis. When they are facing a challenge afterwards, they can use the S paper to elicit the feeling of safety again (Böhmer and Schmidt, 2021; Schmidt et al., 2024a). In another study, we tied the feeling of remembering easily to a piece of paper where participants write the letter E for easy remembering on during hypnosis. When they had to remember the words they just learned, they could use the E paper to make it easier to remember (Schmidt et al., 2024a). In our study, we let participants of the hypnosis group listen to an audio-recorded hypnosis session at home before the race started. We suggested athletes during this hypnosis session that they feel in their optimal mental state to perform on their next race. Then, we established an individual eliciting trigger like pulling the brakes of the bike before the race starts to elicit the feeling of an optimal race. That means the athletes can activate their mental pole position without anyone noticing it on race day just by the routinely movements.

Several studies have investigated sport performance after different hypnosis interventions or a single hypnosis intervention. In controlled studies and single-case design studies, positive effects of hypnosis on athletic performance have been found in different sports, for instance in basketball (Schreiber, 1991; Pates et al., 2002), golf (Pates and Maynard, 2000; Pates et al., 2001b), archery (Robazza and Bortoli, 1995), badminton (Pates and Palmi, 2002) and weightlifting (Lee Howard and Reardon, 1986). However, very few studies have investigated the effect of hypnosis on the optimal performance state in competitions to date (Schreiber, 1991; Lindsay et al., 2005; Pates, 2013; Mattle et al., 2020). No studies have investigated the effects of a hypnosis intervention in mountain biking. Finally, hypnosis interventions seem to be more effective for dexterity, coordination and technical sports (Milling and Randazzo, 2016). Downhill Mountainbike is a sport that requires automatic control of precise movements, fine motor skills, timing and decision making. Thus, we expect a hypnosis intervention to be a successful method to induce an optimal performance state and flow in a downhill Mountainbike race.

Arousal and the experience of flow can be measured via self-reported questionnaires. Additionally, heart rate variability (HRV) as a biomarker provides an inside of the athlete's physiological changes caused by emotional and cognitive processes (Laborde et al., 2018; Balaban, 2019). It reflects continuous fluctuations in beat-to-beat intervals and presents parameters to quantify the sympatho-vagal balance of the autonomic nervous system (ANS). Changes in HRV can be used to assess anxiety-state changes and performance (Murray and Raedeke, 2008; Mateo et al., 2012; Morales et al., 2013). The relationship between competitive anxiety measured by the Competitive State Anxiety Inventory-2 Revised (CSAI-2R) and HRV has been found in Bicycle Moto Cross (BMX; (Mateo et al., 2012)) and judo athletes (Morales et al., 2013). Therefore, HRV provides an economic tool to assess arousal in a competition (Murray and Raedeke, 2008).

In the present study, we developed an audio-recorded hypnosis intervention to induce an optimal performance state in downhill Mountainbike athletes outside of their competition. We selected athletes that participated in two consecutive official races. Participants in the hypnosis group received the hypnosis intervention between both races, the control group did not. We assessed anxiety, self-confidence, stress and HRV in the hypnosis group to compare their mindset in the two races to test if the hypnosis intervention successfully elicited an optimal mental pole position in the second race.

Figure 1 visualizes the content of our hypnosis intervention. To explore the effects of the intervention, we compared self-reported competitive anxiety, self-confidence, stress, resilience, and flow in two races before and after the hypnosis audio-intervention. Additionally, we recorded HRV data in two races before and after the intervention to assess the physiological state of the athletes before the race.

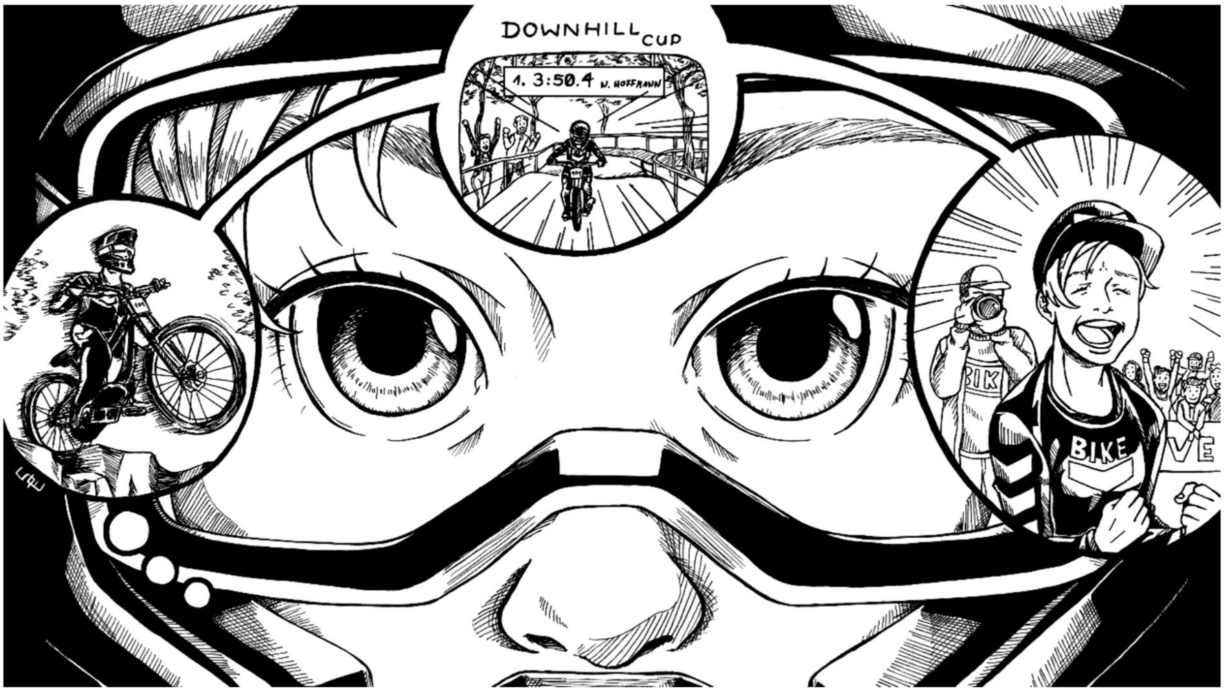

FIGURE 1
Visualization of the hypnosis intervention. Downhill Mountainbike athletes imagine an optimal race, their finish and most importantly, the feeling of success after an optimal race. These mental images are associated with a personal trigger, so the athletes can activate their optimal performance mode before the race starts.

We expected reduced feelings of competitive anxiety and stress before the race, as well as enhanced self-confidence and resilience. Furthermore, we predicted a higher flow state level during the race and expected changes in the parameters of HRV associated with parasympathetic activity. Finally, we expected race performance to be enhanced.

Methods

Participants

Based on the effect size of post-hypnotic suggestions on subjective ratings in previous studies conducted in our laboratory (Böhmer and Schmidt, 2021; Schmidt et al., 2024a,b), we performed a power analysis with G*power resulting in a required sample size of 17 participants to detect an effect of $d = 0.7$ in a within-subjects design ((Faul et al., 2007); $d = 0.7$, $alpha = 0.05$, $power = 0.85$). Via social networks (Instagram), we recruited downhill Mountainbike athletes who participated in two consecutive downhill Mountainbike races. Our final sample consisted of 19 downhill Mountainbike athletes (5 female) all competing on national level who voluntarily took part in the study. The athletes' age ranged between 15 and 36 years ($M = 20.4$, SD = 5.57) and they trained between 2 and 20 h weekly ($M = 13.05$, SD = 4.08). They had between 0.5 and 7 years of race experience ($M = 3.88$, SD = 2.08) and raced between 2 and 13 races per year ($M = 7.25$, SD = 2.99). Half of the athletes ($N = 10$) had experience in international competition with five athletes on World Cup level. Two athletes had experience with mental training. None of them had experience with hypnosis.

The study was approved by the local ethics committee of the Jena University Hospital, with reference number 2022-2568-BO. All athletes filled an informed consent statement and then completed an online questionnaire prior to the races to gather demographic data, training frequency, race experience, hypnosis experience and a trait anxiety score, via the "Wettkampf-Angst Inventar Trait" (WAI-T; Brand et al., 2009). All further data were collected at the IXS Downhill Cup, which is the highest national series of downhill Mountainbike racing in Germany. Athletes can compete at this series either in an open category (recreational category, accessible to all riders) or a license category (elite category, only accessible with a race license). All athletes except of two raced in the license category.

Experimental design

We used a within-subject design with a pre and post measurement of the same participants (Figure 2). The first race was the pre measurement (race 1) to measure baseline performance. After that, participants listened to the hypnosis audio-intervention, followed by a post measurement (race 2). The pre measurement took place at the IXS Downhill Cup in Willingen 2022. One hour before the race, athletes filled in a questionnaire, and we measured heart rate variability. Immediately after the race, athletes filled in a second questionnaire. After the pre measurement, athletes listened to the audio-hypnosis at least once until the post measurement during the

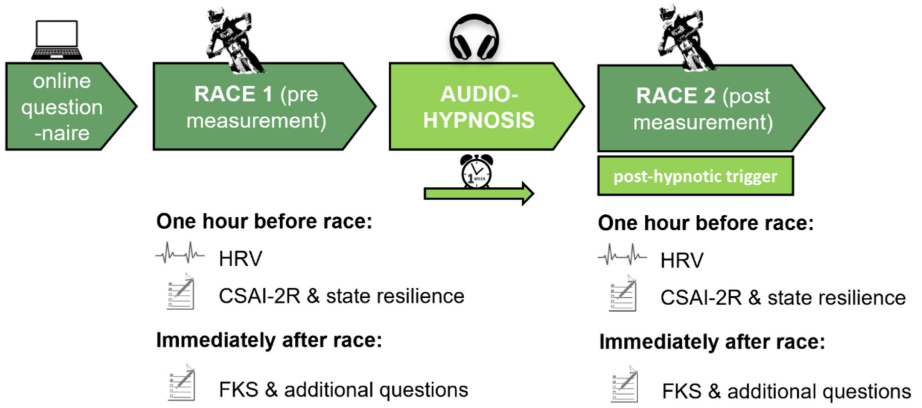

FIGURE 2
Experimental design and study procedure.

next race. The post measurement took place at the IXS Downhill Cup in Winterberg 2022 1 week after the first race.

Race performance measurement

In a downhill Mountainbike race, time to complete the race track is the dependent variable to assess performance. The athlete with the shortest time to complete the track wins the race. In our study, placement and time behind the winner of each category provided the assessment for performance. As a control group, we used the official race tables of both races and compiled a group consisting of athletes who participated in both races (pre and post measurement) but did not officially participate in our study and accordingly did not receive the hypnosis audio-intervention. Our hypnosis group included all athletes who participated in both races (pre and post measurement) and received the hypnosis audio-intervention. We compiled a new placement table for each race including only athletes of hypnosis and control group to compare their performance between races. Time behind the winner of each category was set in relation to total race time of the winner of each category (variable TIME) to achieve a fair proportional ratio of performance between both race as track length differed.

Competitive anxiety, self-confidence, state resilience and flow measurement

One hour before the race run each athlete filled the German version of the Competitive State Anxiety Inventory-2 Revised (CSAI-2R; (Cox et al., 2003)) to measure competitive anxiety and self-confidence. In addition, a state resilience questionnaire (Schwerdtfeger and Dick, 2019) was filled to measure state resilience and subjective stress before the race.

Immediately after the race each athlete filled the Flow Kurzskala (FKS; (Rheinberg et al., 2019)). Moreover, we asked questions regarding the subjective assessment of the athlete's race run performance. In the post measurement athletes additionally rated the hypnosis audio-intervention.

HRV recording and processing

Resting heart rate variability (HRV) was measured 1 h before the race run to assess physiological stress levels in each athlete. A Polar H10 chest strap (Speer et al., 2020) was connected to the Polar Sensor Logger Application (Jukka Happonen, available in Google Play Store) to record HRV data. Athletes were sitting on a chair, instructed to be quiet and calm. After 1 min of resting the 5 min measurement started. All athletes were asked to voluntary wear the chest strap during their race run to collect additional HRV data. This data has only been used for explorative analysis.

We analyzed all HRV data with Kubios HRV Standard version 3.5.0 Analysis Software (Tarvainen et al., 2013). The middle 4 min of the recorded resting HRV were applied for each athlete to reduce artifacts. For each dataset with more than 5% artifacts low threshold smoothing was applied. For HRV time domain analysis, we analyzed heart rate (HR), mean RR interval (MEANRR) and root mean square of successive differences (RMSSD). For HRV frequency domain analysis, we applied autoregressive modeling (Laborde et al., 2017). The normalized power (n.u.) of high frequencies (HF_{nu}) and the ratio of low frequencies to high frequencies power (LF/HF ratio) were analyzed to estimate the sympatho-vagal balance of the ANS.

Hypnosis and establishment of post-hypnotic trigger

We provided the hypnosis intervention as an audio-intervention. The first part of the original recording of the hypnosis audio-intervention is accessible via this link[1]. Nina Hoffmann, the first author of the study and herself a well-known MTB athlete, recorded the audio-intervention. As Nina Hoffmann won four times the German national championship and became vice world champion in downhill Mountainbike, she was perceived as a very competent person and achieved high rapport in our participating athletes. During the

1 https://www.nina-hoffmann.com/mental

week between both races, we instructed the athletes of the hypnosis group to listen to our hypnosis intervention. They were encouraged to find a quiet room with a comfortable seat and listened to the audio tape on their own. To induce a hypnotic state, we followed the hypnosis induction of the Stanford Hypnotic Susceptibility Scale, Form C (Weitzenhoffer and Hilgard, 1962). Afterwards, we used a time progression method that establishes positive imaginations of the future. The athletes were suggested to imagine their next race in an optimal way. Therefore, athletes thought at first about the intense positive feelings of joy, luck, pride, and success in the finish area after completing an optimal race run. From there we went into their race run imagined in an optimal way always evoking the positive feeling from the finish area. Finally, we imagined the last minutes before the race start when nervosity is the highest and again, transferred this arousal into the positive feeling from the finished area. At the end, these feelings were tied to an individual personal anchor. We counted from 1 to 10 to enhance the positive feelings one last time and then encouraged the athlete to find a personal ritual or routine that could easily be established in their warm-up routine at the next race. We gave some examples like pedaling backwards on the bike, pulling the brake lever, listening to a certain song, or slamming on the chest. Athletes were allowed to choose any personal anchor they had in mind. This allows a reactivation outside the hypnotic state, for example before their next race start. Finally, athletes were led out of the hypnotic state. Athletes were allowed to listen to the audio-hypnosis as often as desired, but at least once. The audio-hypnosis session lasted about 35 min.

Statistical analysis

Statistical analysis was performed using R version 4.2.2 (R Core Team, 2022). We compared the performance data, self-reported data and HRV data of baseline and post measurements conducting paired-samples *t*-tests. Race performance of hypnosis and control group has been compared conducting Welch's *t*-tests. In addition, we analyzed the evaluation of the established post-hypnotic trigger. To quantify effect sizes Cohen's *d* for within-subjects *t*-tests was computed. For all analyses, a *p*-value of <0.05 was considered statistically significant.

Results

Race performance data

Athletes of the hypnosis group ($N = 19$) showed significantly better performance compared to athletes of the control group ($N = 108$) at both races. Specifically, we found better placements in the hypnosis group (first race: $t(52.29) = 4.15$, $p < 0.001$, second race: $t(38.01) = 4.4$, $p < 0.001$) and faster race times, assessed via our TIME variable (first race: $t(59.9) = 2.21$, $p = 0.03$, $d_z = 0.34$; second race: $t(43.42) = 3.03$, $p = 0.004$, $d_z = 0.49$).

The performance of both groups did not improve from first to second race. There was no improvement in placement ($t(17) = 0.62$, $p = 0.54$) and TIME in the hypnosis group ($t(17) = 0.35$, $p = 0.73$). The performance results of the control group did not improve (placement: $t(107) = 0.28$, $p = 0.78$; TIME: $t(107) = 0.52$, $p = 0.6$). There were no significant changes in the hypnosis group in self-reported mistakes ($t(18) = 0.37$, $p = 0.72$) and crashes ($t(18) = 1$, $p = 0.33$) during the race run.

Competitive anxiety and self-confidence

Athletes in the hypnosis group rated their anxiety and self-confidence before each race. Results of the CSAI-2R are shown in Figure 3. Athletes showed significantly less somatic anxiety after listening to the hypnosis audio-intervention, revealed by a reduction of CSAI-2R somatic anxiety scores from 2.4 (SD = 4.81) at the first race to 1.93 (SD = 5.46) at the second race on a 4-point Likert scale ($t(17) = 3.36$, $p = 0.004$, $d_z = 0.79$). There were no significant changes in cognitive anxiety between races: $t(17) = 0.88$, $p = 0.43$.

Self-confidence, shown in Figure 4, increased significantly after listening to the hypnosis audio-intervention, shown by increased CSAI-2R self-confidence scores from 3.07 (SD = 4.74) at the first race to 3.23 (SD = 4.2) at the second race on a 4-point Likert scale: $t(17) = 1.89$, $p = 0.04$ (one-tailed), $d_z = 0.45$. After finishing the race, athletes filled an additional questionnaire about their subjective feelings of their race performance and feelings immediately before the race start on a 5-point Likert scale ranging from 1 ("I fully agree") to 5 ("I fully disagree"). There was a significantly higher agreement to the sentence: "I was self-confident before my race start." changing from 2.23 (SD = 1.0) at the first race to 1.79 (SD = 0.97) at the second race: $t(17) = 1.93$, $p = 0.04$ (one-tailed), $d_z = 0.58$.

As an exploratory analysis, we investigated gender effects on self-confidence. We found that only female's CSAI-2R self-confidence scores improved equivalent to 0.58 points on 4-point Likert scale from 2.7 (SD = 0.59) to 3.3 (SD = 0.53) points. The self-confidence scores of the male athletes did not change (first race: $M = 3.2$, SD = 0.36, second race: $M = 3.2$, SD = 0.4).

Flow state

The scores of the FKS showed no changes between races in flow state ($t(18) = 0.14$, $p = 0.89$) and concerns ($t(17) = 0.79$, $p = 0.44$).

State resilience and subjective stress

The state resilience questionnaire showed no significant changes from first to second race in state resilience: $t(18) = 0$, $p = 1$. Subjective stress before the race, shown in Figure 5, decreased significantly after participants listened to the hypnosis audio-intervention: $t(18) = 3.33$, $p = 0.002$, showing a large effect size of $d_z = 0.76$.

HRV data

We found a significant decrease in heart rate by 3 bpm from first to second race: $t(18) = 1.75$, $p = 0.049$ (one-tailed), $d_z = 0.32$. There were no significant changes in MEANRR ($t(18) = 1.99$, $p = 0.06$) and RMSSD ($t(18) = 0.93$, $p = 0.36$).

Concerning HRV, we found significant changes in HF_{nu} and LF/HF ratio. There was a significant increase in HF_{nu} from first to second race: $t(18) = 2.64$, $p = 0.02$, $d_z = 0.61$. In line with that, we also found a

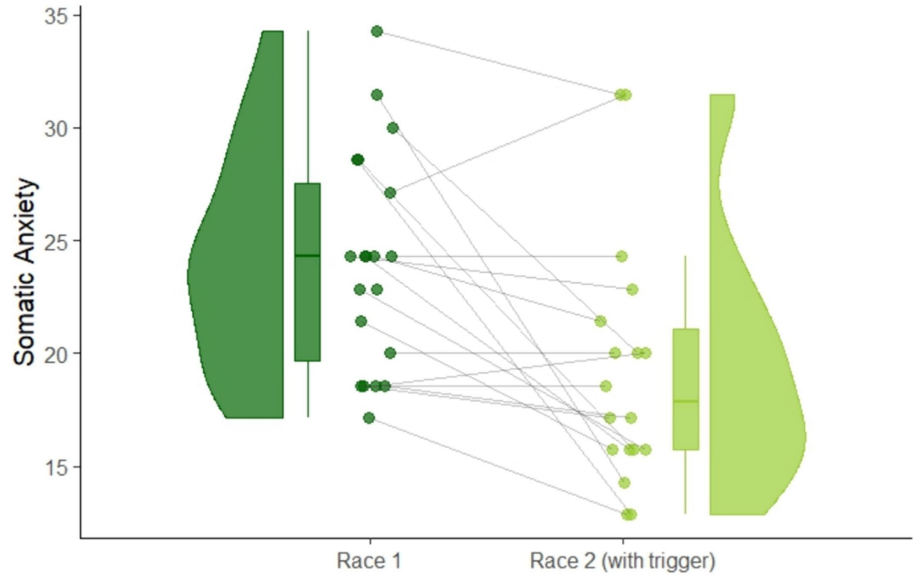

FIGURE 3
Raincloud plot of within-subject changes of somatic anxiety scores measured via CSAI-2R from race 1 to race 2.

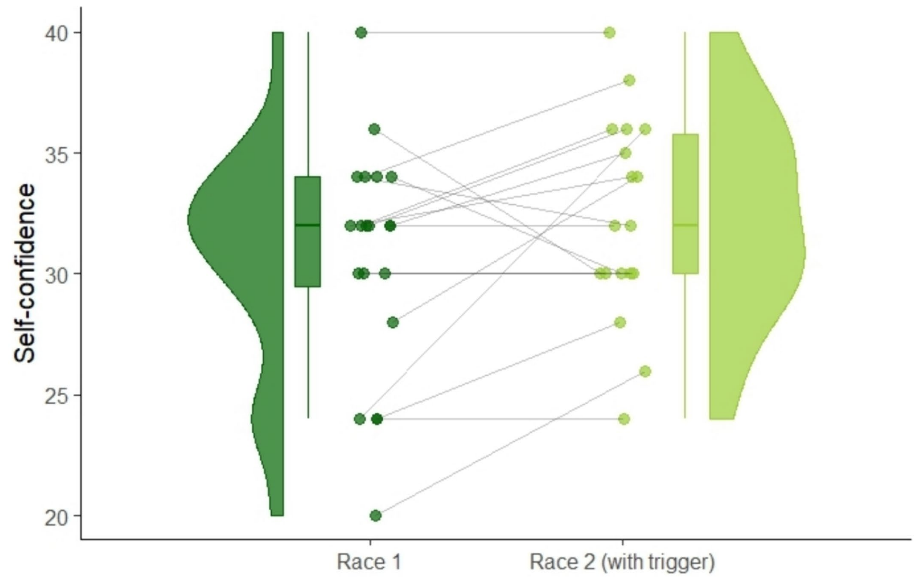

FIGURE 4
Raincloud plot of within-subject changes of self-confidence scores measured via CSAI-2R from race 1 to race 2.

significant decrease in LF/HF ratio from first to second race: $t(18) = 3.26$, $p = 0.004$, $d_z = 0.75$, Figure 6. These results indicate lower sympathetic and higher parasympathetic activity after athletes listened to the hypnosis audio-intervention.

Evaluation of the audio-hypnosis

Athletes evaluated their perceived feelings of the hypnotic trance and the efficacy of the post-hypnotic trigger after finishing the second race on a 5-point Likert scale ranging from 1 ("I fully agree") to 5 ("I fully disagree"). All athletes agreed that they were able to engage well with the hypnosis audio-intervention ($M = 1.42$, $SD = 0.51$). Most of the athletes ($N = 14$) agreed that they were able to use the post-hypnotic trigger well before their race run ($M = 1.95$, $SD = 0.78$). Almost the same number of athletes ($N = 12$) reported that they felt safer before the race start with using the trigger ($M = 2.21$, $SD = 0.71$) and again $N = 12$ athletes had the subjective feeling the trigger affected their race performance ($M = 2.21$, $SD = 0.85$). Athletes reported they felt that pressure has been taken away during the whole race weekend. They reported less self-doubts, were able to smile on race day and had a positive mindset about the upcoming run. One athlete mentioned

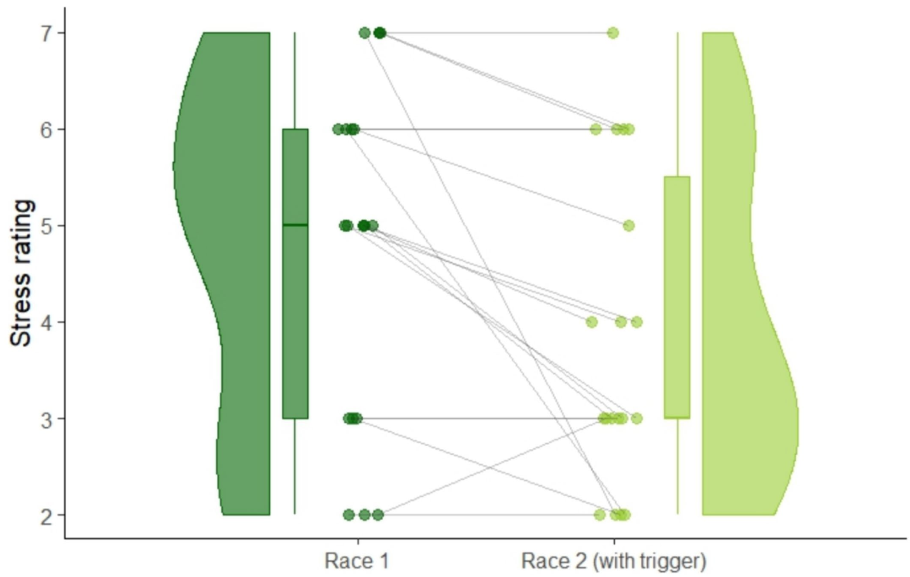

FIGURE 5
Raincloud plot of within-subject changes of self-reported ratings of stress before the race from race 1 to race 2.

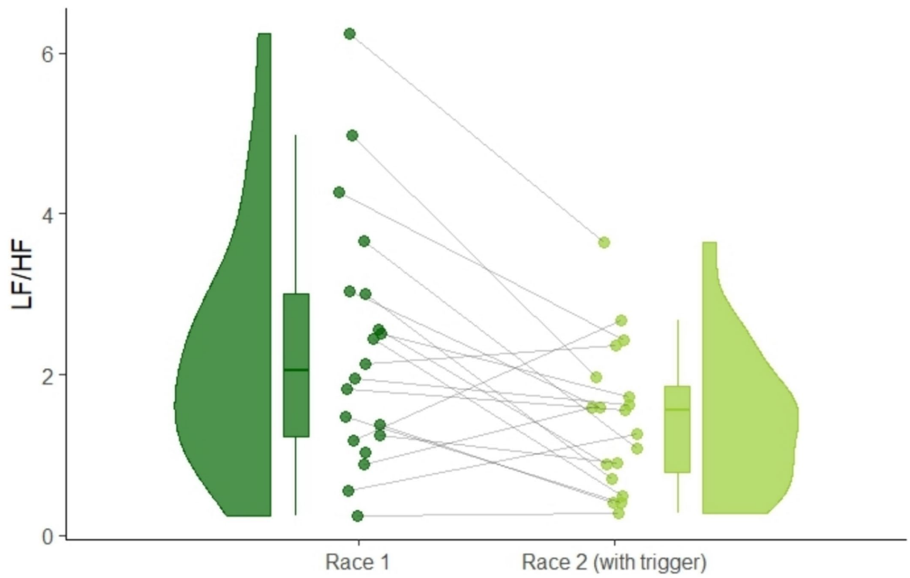

FIGURE 6
Raincloud plot of within-subject changes of LF/HF ratio from race 1 to race 2 as an indicator of increased parasympathetic activity.

he had the feeling that some burden has been taken off the shoulders before the start. Another one thanked the research team for providing a method that can be used in any situation where the nervous are getting high. The athletes listened in average 3 times ($M = 2.94$, $SD = 1.73$) to the audio-hypnosis for 1 week.

Discussion

In our present study, we present a hypnosis intervention designed to help athletes to start in their mental pole position. We tested the effect of this intervention on athletes' subjective ratings, physiological measures and performance in two official consecutive downhill races. Athletes of the hypnosis group filled in questionnaires and listened to the hypnosis audio-intervention in between both races, athletes of the control group did not. We expected that our hypnosis intervention reduces competitive anxiety and stress, as well as enhances self-confidence and resilience before the start of the second race. Furthermore, we predicted that athletes in the hypnosis group experience higher levels of flow state during the second race. We also expected changes in HRV parameters that are associated with parasympathetic activity measured 1 h before the race. Finally, we presumed to improve race performance in the hypnosis group.

We found significant reductions of somatic anxiety and stress in the hypnosis group. Athletes also showed significantly enhanced self-confidence in the race following the hypnosis audio-intervention. Athletes' heart rate variability increased significantly after they listened to the hypnosis audio-intervention, which is a sign of more parasympathetic activity and thus better stress resilience. We did not find higher flow state levels after the hypnosis intervention and race performance did not improve in the hypnosis group compared to the control group. Overall, we conclude that the present study provides a quantitative proof of the positive effects of a hypnosis audio-intervention on elite downhill Mountainbike athletes. Our intervention helps athletes to deal with the high pressure associated with a downhill Mountainbike race. Our findings contribute to the existing literature on the positive effects of hypnosis on sport performance and well-being in sport (Milling and Randazzo, 2016). Combining the setting of two real bike races and the experimental assessment of subjective ratings and physiological data conducted in that setting results in high ecological validity of our findings. Our intervention is thus a promising technique to improve athletes' mental strength and activating their inner resources of power, pride and flow that gets them in the mental pole position.

Race performance

We were expecting that our hypnosis audio-intervention increases athletes' mental strength on the race day and therefore improves race performance in the hypnosis group. The hypnosis group performed better than the control group at both races. This might reflect a selection bias as especially good athletes are highly motivated to improve performance with new techniques (Atkinson and Nevill, 2001). However, we did not find any improvements of race performance in the hypnosis group after they listened to the hypnosis audio-intervention. Results of a downhill Mountainbike race depend on many different variables like physical exertion, track and weather conditions, bike material or competitors (Chidley et al., 2015). Mental strength is one variable to influence race performance. Furthermore, our hypnosis intervention has only been given to the athletes for 1 week. A longer period would give our hypnosis intervention more time to unfold its potential with athletes being able to manifest their mental pole position before races (Schmidt et al., 2024b), integrate it in their training and perhaps improve race performance.

Competitive anxiety, self-confidence, and flow state

Empirical research showed that competitive anxiety is more detrimental to sports that require coordination and fine motor skills (Mellalieu et al., 2006). downhill Mountainbike adds to those types of sports with requiring high cognitive capacities. Thus, a low level of competitive anxiety and arousal should help athletes reaching their IZOF. With our hypnosis intervention we were able to lower the feelings of somatic anxiety before the race.

The hypnosis audio-intervention did not affect cognitive anxiety levels. Hypnosis elicits changes in individuals on an unconscious or subconscious level, which manifests in emotional and somatic changes (Schmidt et al., 2021). Cognitive changes in turn are conscious, what could explain why cognitive anxiety has not been affected. One of the athletes reported to not remember the personal trigger but suddenly had the desire to listen to one specific song before the race. This exemplary shows that hypnosis works in an un- or subconscious way.

We were able to raise self-confidence levels from first to second race. Our audio-hypnosis included the activation of feelings of pride and happiness before the race, which perhaps leaded to the increase in self-confidence. As self-confidence being one of the most important variables for descending time in downhill Mountainbike an increase of self-confidence is a strong achievement (Chidley et al., 2015). Additionally, an increase in self-confidence and the recall of an optimal performance may serve as a buffer against competitive anxiety and help athletes to deal better with the pressure of a competition (Milling and Randazzo, 2016).

We did not find any changes in flow state. To enter a flow state anxiety and stress levels must be low and on an individual optimal level (Nakamura and Csikszentmihalyi, 2009). We were able to reduce both, stress and anxiety, but the post measurement took place only 1 week after the intervention. This may have been too early to elicit changes in flow state.

HRV data

Anxiety and competitive stress situations lead to a decrease of vagal activity which can be measured using HRV parameters (Morales et al., 2013). With our hypnosis intervention we tried to reduce anxiety and stress levels and enhance parasympathetic nervous system activity 1 h before the race. By the time we conducted the resting HRV measurement athletes had not started their warm-up yet, so a calm and relaxed mindset is desirable. We showed an increase in HF_{nu} and a decrease of LF/HF ratio before the second race. Hence, athletes felt more relaxed and less stressed leading to higher resilience 1 h before the second race. This is a desirable outcome as elevated stress levels harm mental health and can lead to an increased risk of injury (Ivarsson et al., 2017). Especially downhill Mountainbike athletes are delicate for injuries with downhill Mountainbike being high-risk sport and injury prevention has highest priority (Guszkowska and Boldak, 2010).

Hypnosis audio-intervention

All athletes listened to the audio-hypnosis themselves at home in a quiet room between the two competitions. After the second race, they rated their subjective experience with the hypnosis session on a 5-point Likert scale in four self-developed sentences, such as "I was able to dive well into the hypnotic trance," "I had the feeling the hypnotic intervention helped me in my next competition," "I was able to use the post-hypnotic trigger before my next race" and "I felt safer before the race with the use of my post-hypnotic trigger." The hypnosis intervention has been accepted well by all athletes. Every athlete was able to engage well with the hypnosis intervention and most of them ($N = 12$) rated the individual trigger as an effective tool before the race start to provide safety and enhance performance. Qualitative feedback given to the experimenter by each athlete after the second race was primarily positive. All but three athletes were sure that the hypnosis intervention was helpful and effective. This subjective feedback shows that this audio-intervention might be an appropriate tool for a majority of downhill Mountainbike athletes.

We did not test hypnotic susceptibility in the athletes. All athletes participated voluntarily in the study. There has been high curiosity, a positive attitude, and high expectations of hypnosis, which has been shown to be important predictors of hypnotic responding (Kirsch et al., 1995). The motivation of all athletes to engage with the hypnosis intervention has been high due to a real race setting. Furthermore, high rapport has been created by recording the audio-hypnosis by Nina Hoffmann. Hence, we expected athletes to be highly susceptible for hypnosis.

Two hypnosis interventions can be classified as efficacious for enhancing sports performance (Milling and Randazzo, 2016). In our study, athletes listened on average three times to the audio-hypnosis ($SD = 1.73$, range = 1–7). As none of the athletes had experience with hypnosis, many reported easier engagement with the hypnosis intervention when listening the second time. This indicates that a longer period with more hypnosis session may have larger effects. However, we found no significant correlations between the times athletes listened to the hypnosis intervention and somatic anxiety, self-confidence, subjective stress or HRV data.

Future directions

Our study represents an innovative approach and has high ecological validity. The inclusive nature of our sample population strengthens the external validity of our findings and underscores the relevance of hypnosis as a performance-enhancing tool for a broad spectrum of athletes. The intervention focused on competitive performance in an unconventional sport setting and all effects have been detected in a real downhill Mountainbike race setting. Thus, our intervention provides a robust and effective method for downhill Mountainbike athletes to improve variables that can foster athletic performance. As we conducted a field study, there are a few limitations. First, there has been no control group for all self-recorded data and HRV measurement. Since we acquired data in a real competition setting, we did not want to interfere in athletes race routines of the control group with providing questionnaires and a placebo audio tape. Therefore, we can only compare hypnosis and control group based on their official performance tables. We did the best to rule out possible alternative explanations and used a within-subjects design to measure intraindividual changes. Second, we did not collect individual baseline HRV data outside a competition or in the morning of the competition because of lacking capacity. Third, our post measurement took place only 1 week after the pre measurement. A longer time period between both races where athletes use the hypnotic intervention could have led to measurable performance improvements. Finally, the hypnosis intervention has been provided as an audio recording. An individual hypnosis intervention with each athlete could elicit larger effects and perhaps improve race performance (Robazza & Bortoli, 1995; Pates et al., 2001a; Pates, 2013). Future research is needed to investigate the positive long-term effects of hypnosis interventions on downhill Mountainbike athletes, their mental health and race performance.

Conclusion and practical implications

The results indicate that our hypnosis audio-intervention is an economic and effective method to induce an optimal performance state in elite downhill mountain bike athletes. We enabled the athletes to harness the positive feelings, enthusiasm and energy they get from mountain biking, which helped them coping with the pressure on race day. The reduced anxiety and increased self-confidence as well as lower subjective and objective stress levels helped the athletes to achieve optimal performance in the competition.

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 in the article/supplementary material.

Ethics statement

The studies involving humans were approved by local ethics committee of the Jena University Hospital, with reference number 2022-2568-BO. 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

NH: Writing – review & editing, Writing – original draft, Investigation, Conceptualization. JS: Writing – review & editing, Supervision. BS: Writing – review & editing, Supervision.

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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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How expressive ties energize competitive performance in DanceSport dyads: unraveling the role of athlete engagement in an innovatively applied actor-partner interdependence mediation model

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Objectives: This study explores the significant impact of expressive ties (EI) between DanceSport couples on their competitive performance (CP). Utilizing a dyadic approach, we examined the performance achievement processes of DanceSport couples in relation to their EI.

Methods: Participants comprised 67 dyads of Chinese elite dancers aged between 16 and 30 years. The dyadic analysis was carried out using a structural equation model based on the actor-partner interdependence mediation model.

Results: With regard to actor effects, both male (β = 0.292, p = 0.012) and female (β = 0.443, p < 0.001) dancers' perceived quality of EI had a positive correlation with CP. The males' athlete engagement (AE) partially mediated the impact of EI on CP [indirect effect = 0.144, SE = 0.072, 95% confidence intervals (CI) = 0.020, 0.283]. Regarding partner effects, females' perceived EI quality positively influenced the male's CP (β = 0.26, p = 0.023) and mediated this association through the male's AE [indirect effect = 0.086, SE = 0.041, 95% confidence intervals (CI) = 0.003, 0.149]. Similarly, the females' AE mediated the effect of males' perceived EI quality on the females' CP [indirect effect = 0.152, SE = 0.074, 95% confidence intervals (CI) =0.002, 0.256].

Conclusion: We not only validated the propositions of the self-determination theory but also provided valuable insights to further enrich it. Our findings underscore that self-determination theory must account for individual gender characteristics.

KEYWORDS

APIM, partnership, expressive ties, competitive performance, athlete engagement

Introduction

Dance Sport, which is another name for competitive dance, is a stunning illustration of love desire. It is an open presentation of feelings, influenced by themes of sensuality and love (Harman, 2019). It emphasizes the intimate ballet between male and female partners, celebrating the pleasurable tension and harmony between them (Ericksen, 2011). DanceSport, a sophisticated form of male–female partnered dancing (Ogilvie, 2017, pp. 3), places romance as its utmost essence (John, 1998, pp. 11; Marion, 2014). Hence, the predominant aesthetic in partnered dance, particularly in ballroom, is the twinned collaboration between men and women (Marion, 2006; Budnik-Przybylska et al., 2015). In summarize, the cooperation between partners is the most important feature of sports dance, and emotional skills training is very important (Dan, 2012; Sun and Wu, 2023). So, the analysis of various problems surrounding DanceSport must always consider the partnership between couples (Pilewska et al., 2013). Yet, the connection between expressive ties and competitive performance in DanceSport pairs remains undefined. As a result, this research utilizes the Actor-Partner Interdependence Model (APIM) to delve into the association of expressive ties with competitive performance in DanceSport pairs and to assess gender differences. This could provide a theoretical framework for formulating distinctive interaction strategies for men and women in the future, as well as further enrich the theory of competitive behavior.

Expressive ties between DanceSport dyads and competitive performance

Expressive ties, which incorporate two key factors – instant intimacy and long-term affection (Ericksen, 2011), play a pivotal role in influencing competitive performance (Liu et al., 2023). Instant intimacy is defined as a fleeting yet intense state of desire developed amidst the competition, forged between dance partners. It could stem from romantic attraction or a shared dedication to the dance form (John, 1998). Studies on event-related potentials (ERPs) have established that the brain's electrical components react when individuals process information regarding others with whom they share a high level of intimacy. Notably, the N2 component (Chen et al., 2013), which signifies familiarity, and P3 (Matsunaga et al., 2012), associated with emotions, display elevated amplitudes. Moreover, fostering a potent sense of passion (Baumeister and Bratslavsky, 1999) is considered essential for excellent performance. High-level competitors often channel the intensity of romance between the sexes in dance by expressing passion for their partners, particularly during their performance (Liu and Wang, 2022; Liu et al., 2023). It is also finds that those with more frequent dance habits or elite dancers score higher on the expressive ties (Izountouemoi and Esteves, 2023).

The influence of instant intimacy on DanceSport competitive performance gains corroboration from neuroscientific research as well. The mirror neuron mechanism comes into play here, with specific regions of the human cerebral cortex, such as the inferior parietal lobule, the anterior Bocca region before the ventral motor, and the posterior segment of the inferior frontal gyrus exhibiting a "mapping" functionality of mirror neurons (Fogassi, 2011; Ye et al., 2016). This mapping mechanism translates the subtle sensual nuances of couples' movements, like their entwined bodies, captivating eye-contact, synchronized breathing, and burgeoning passion, into emotional catalysts augmenting their partnership. The implications and significance of these minutiae of movements requires deeper perspective. DanceSport participants use a plethora of subtle to blatant cues to signify romantic interest, such as touching intimate body parts like the lower hips and buttocks, maintaining full-body contact, stroking the partner's hair or face, dancing cheek to cheek, or maintaining intense eye contact, along with other unique gestures. (Joanna Bosse, 2015, pp. 61). Meneau (2020) provides an evocative description of an intimate dance movement: "He approaches her from behind until his chest touches her back, then thrusts his hands to her lower thighs and caresses her upwards. After grabbing her waist, he pushes her away and pulls her back to him, provoking an impact of her back against his ribcage." Building on these sensual movements, Peters (1992) highlights the confusion dancers might experience due to the sexual tension on the dance floor, questioning the nature of their off-stage relationship. Moreover, Heyes and Catmur (2022) point out that mirror neuron-associated brain regions are crucial for simulating physical movements. Thus, when dancers showcase their sensual movements, the mirror neurons in their partners react, intensifying the intimacy of their performance.

Long-term affection signifies an emotional bond developed over prolonged interactions in both personal and professional spheres between dance partners. This varies from instant intimacy due to its more diluted emotional intensity and gradual emotional manifestation (Liu et al., 2023). Such long-term affection necessitates that the dancers' esteem, care for, and harmonize with their partners. This is akin to the "partner care dimension" of DanceSport couples' partnership (Myung et al., 2010), the "closeness dimension" in the 5C's theory of athlete-athlete partnership (Poczwardowski et al., 2019), and also parallel to the 3C's theory of the coach-athlete relationship (Jowett and Meek, 2000; Jowett and Cockerill, 2003; Jowett and Ntoumanis, 2004; Jowett and Poczwardowski, 2007; Jowett and Palmer, 2010). Key to maintaining a consistent training schedule, it paves the way towards achieving superior performance.

This may have its origins in the way that people are naturally "sociable," a trait that society bestows on all people. Particularly for elite dancers, who often undertake training sessions over a decade or even two decades with same partner, this becomes salient. These dancers frequently relocate from their homes to other places for training, often independently without the backing of any organizations. So, they are compelled to support each other, practice tolerance, and forge a harmonious relationship model shaped by the trials of shared fortunes or misfortunes. Often, over this journey, they establish close emotional ties, such as romantic relationships.

When dancers feel understood and valued, their mutual intimacy escalates (Fitzsimons and Kay, 2004). Therefore, it becomes imperative for partners to exude both passion and emotion in their performance. It was frequently noted that classically trained dance couples also shared their lives off-stage (John, 1998, pp. 117; Majoross et al., 2008; Brewińska and Poczwardowski, 2012). A study discovered that among international professional dancers, a majority of couples were married and rarely described their bond as working relationships (Majoross et al., 2008). Additionally, research examining the social and psychological characteristics of dyadic participants revealed superior performances if the members fostered mutual likability (Krivonos et al., 1976).

Mediating variable: athlete engagement

Interpersonal relationships provide the environment for cognitive sharing and performance enhancement (Davis et al., 2018; Staff et al., 2020). According to the motivation-hygiene theory, while interpersonal relationships serve as a hygiene factor that bolsters performance, under certain circumstances, they can transform into a motivating factor. This suggests the presence of mediators that facilitate the transition of interpersonal relationships into competitive performance-one of which is Athlete Engagement (AE).

Conceptualized from a positive psychology perspective by Lonsdale et al. (2007a,b), AE encompasses a persistent, positive, cognitive-affective state. It is characterized by the presence of confidence (belief in one's ability to achieve high-performance levels and desired goals), dedication (the willingness to invest time and effort to fulfill important goals), vigor (a feeling of physical and mental vitality), and enthusiasm (intense excitement and enjoyment). Lonsdale et al. (2007a,b), based on the self-determination theory, proposed a strong correlation between relatedness and AE, a notion endorsed by multiple studies (Hodge et al., 2009).

Further supporting this, Ye et al. (2016) constructed a mediating model of AE and Hope, examining the relations between coach-athlete relationship and competitive performance satisfaction (which was self-reported due to the inconsistent performance scale across different sports events). Their study indicated a significant mediating effect of AE ($\beta = 0.04$, $p < 0.001$).

Motivated by this study, we propose that AE mediates the association between competitive performance and DanceSport partnerships. This creates a psychological environment conducive to the transformation of interpersonal relationships into competitive performance. Two reasons substantiate this hypothesis. First, according to the Self-Determination Theory and associated studies mentioned earlier, the fulfillment experienced in a DanceSport partnership, such as the quality of expressive ties, influences training quality and consequently, AE and competitive performance.

Second, studies reveal that athlete engagement, entailing facets like dedication, vigor, and confidence, impacts competitive performance. As observed by Tremayne and Ballinger (2008) in an interview with an Australian championship-level couple, judges tend to favor DanceSport couples who exhibit harmony, vigor, and confidence during competitions (sub-dimensions of AE). Moreover, high-performing dancers generally demonstrate diligence, a firm belief in their success, are goal-confident, and show higher motivation levels (Jackson and Beauchamp, 2011; Ifrar et al., 2020). Jackson et al. (2010) emphasized that sports partnerships are highly goal-oriented in terms of training and competition outcomes, and successful purposeful interaction hinges on joint and sustained dedication to practice, planning, and organization. Thus, desirable partner traits in these contexts include high conscientiousness (being reliable, disciplined, and dutiful). Furthermore, John (1998, pp. 33) asserted that successful DanceSport competitors are both gifted and dedicated athletes.

Mutual influences between the DanceSport dyads and the applied of the APIM

Extant literature posits that interpersonal relationships are essentially dyadic in nature (Berscheid, 1999; Kivlighan, 2007; Reis, 2007; Ferris et al., 2009), with the dyadic structure forming the crux of these relationships (Reis and Collins, 2004). This structure encapsulates the fundamental attributes of interpersonal relationships. Firstly, it implies that the two parties involved are interdependent, considering this mutual dependence in planning their interactions and activities. Secondly, it denotes shared future expectations and distributed responsibilities among the dyads.

In the realm of DanceSport, exceptional performance hinges on the closeness of the partnerships, the mutual influence and dependence between partners, and their capacity to incite potent interpersonal feelings and cognition (Pistole, 2003; Ifrar et al., 2020). Thus, as partner dance forms, DanceSport dyads are thought to inspire each other's emotions and behaviors (Middelberg, 2001). Despite previous studies considering the interaction between DanceSport partners, research on the interaction of such dyadic pairs has long been inadequate due to methodological limitations.

To elaborate, prior studies of dyadic relationships often attempted to analyze individual responses from each member, treating these as independent observations (e.g., analyzing 67 dyads as 134 individual cases) and predicting each individual outcome variable through their own predictor variables. This method overlooked the non-independent nature of dyadic data, thereby jeopardizing the veracity of the analysis (Kenny et al., 2006).

To address this, Kenny and his colleagues devised the Actor-Partner Interdependence Model (APIM; Kenny and Cook, 1999; Cook and Kenny, 2005). This model, an innovative approach to resolving issues of interdependence in dyadic research, distinguishes between partner effects (the influence of a partner's characteristics on another's attributes) and actor effects (the influence of one's own characteristics on their attributes) (Carr, 2012, pp. 98). Through employment of this approach, numerous studies have begun focusing on interactions between dyadic couples.

However, a comprehensive review study revealed a significant dearth of research considering performance as an interpersonal outcome variable. It suggested that sports and workplace domains could redress this gap by fostering performance-enhancing psychological environments within the dyadic relationship sphere (Staff et al., 2017). In light of this, the present study attempts to validate an actor-partner interdependence mediation model, basing its construction on relevant literature.

The current study: development of theoretical framework and hypotheses

DanceSport depictions lean extensively on heteronormative gender performances, featuring distinct romantic interactions between individuals of opposite sexes (Meneau, 2020). DanceSport couples fuse physical agility with artistic expression, giving prominence to emotional expression and mood creation. In fact, emotional expression between partners can often compensate for technical deficiencies (John, 1998, pp. 135). As a pair, dancers must collaborate and express their intentions through the directional flow of energy and pressure at different body points. Their elite performance hinges on their ability to cultivate and stimulate profound interpersonal feelings and cognition (Pistole, 2003). For dancers, the challenge lies within the synchronization of their movements and the atmosphere it generates (Nadel and Strauss, 2003). Therefore, it is proposed that the actor-partner effects of expressive ties significantly impact both male and female competitive performance.

This expression encompasses aspects such as "harmony/rapport," "appreciation," "care," and "passion" between couples, deemed pivotal factors in DanceSport training. John (1998, pp. 27) sates, "harmony/rapport between the dancers is essential, be it driven by romantic attraction or a shared passion for the dance." Mutual "appreciation" between dance partners refers to the shared adeptness in dance skills, serving as a crucial predictor of their competitive performance.

Enduring interaction over time necessitates DanceSport dyads to exhibit "care" towards each other, which aids in achieving win-win competitive outcomes. Furthermore, "passion" between dancers signifies an optimal competitive condition that appeals to the judges, thus securing a favorable score and culminating in superior competitive performance. Even though competition scoring criteria require judges to rate dancers based on body control, posture, shape, footwork, timing, rhythm, and the complexity of the routine (Pittman et al., 2005), these aspects must be evaluated within a limited time frame in an environment where up to 50 couples compete in the initial rounds with judges eliminating 50% of the couples in 2 min.

Achieving excellent competitive performance extends beyond technical accuracy. The crux lies in presenting a harmonious, elegant, and captivating overall impression (Tremayne and Ballinger, 2008). Fostiak (1996) reinforces this by encouraging dancers to "feel your partner," promoting harmony with their partners. Hence, we propose:

> *H1:* male's perceived expressive ties quality will influence his own competitive performance.
>
> *H2:* female's perceived expressive ties quality will influence her own competitive performance.
>
> *H3:* male's perceived expressive ties quality will influence female's competitive performance.
>
> *H4:* female's perceived expressive ties quality will influence on male's competitive performance.

The hypothesis above forms the model shown in Figure 1.

Under the mechanism of mirror neurons, partners exhibit their innate physiological responses during cooperation and interaction, specifically, sexual attraction and flirtation. This sparks a strong short-term passion between dance partners which fuels both their own and their partner's enthusiasm for dance. This non-cognitive element significantly impacts competitive performance. Furthermore, high-quality expressive ties encourage more frequent cooperation between partners, enhancing individual competitive performance and satisfaction with competitive performance. Thus, both males and females can augment their athletic enthusiasm and individual competitive performance through the intense passion displayed on the competition court and their expressions of appreciation, care, and so on. As a result, we put forward the following proposition:

> *H5:* male' athlete engagement partially mediated the effect of his own perceived expressive ties quality on his own competitive performance.
>
> *H6:* female' athlete engagement partially mediated the effect of her own perceived expressive ties quality on her own competitive performance.
>
> *H7:* male' athlete engagement partially mediated the effect of female's perceived expressive ties quality on male's competitive performance.
>
> *H8:* female' athlete engagement partially mediated the effect of male's perceived expressive ties quality on female's competitive performance.

The hypothesis above forms the model shown in Figure 2.

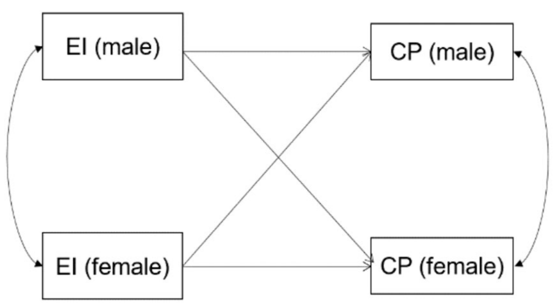

FIGURE 1
The actor-partner effect hypothetical model of athlete dyads' expressive ties on their own and partners' competitive performance.

Methods

Procedure

This study adopted a cross-sectional design and upon receiving institutional ethical approval, participants were canvased via email to partake in the study. Participants received standardized information elucidating the purpose of the study and pertinent ethical considerations including confidentiality, anonymity, the right to withdraw, and data protection.

Participants

Our sample comprised of 134 participants (67 dyads) who took part in the 2019 Chinese DanceSport Championship (Beijing Station), the apex event in Chinese DanceSport hosted at Ditan Gymnasium. We engaged three experienced international-level DanceSport judges to choose the participants for this study based on the competitors' performance abilities. Thus, a pool of 242 competitors was initially selected. The criteria for inclusion included: (a) having a regular partner for at least three years; (b) show of exemplary performance in the past. To minimize distortion due to athletic ability, a second round of screening was carried out, resulting in the selection of 134 participants (67 dyads) with comparable competitive levels for the study.

By proactively communicating with participants as well as their coaches or friends, we secured their trust and backing. After the

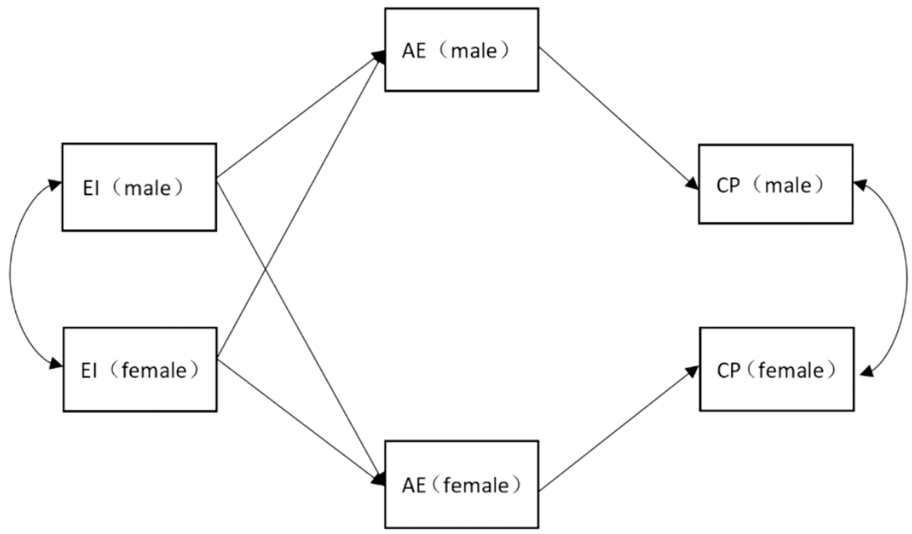

FIGURE 2
The mediated hypothesis model of the effect of expressive ties between couples on competitive performance.

competition, paper questionnaires were distributed right away and electronic versions were given to those who preferred to fill them out later due to the noisy venue and physical exhaustion from competition. Two researchers assisted with data collection to ensure the independence of each person's responses. The participants' average age was 19.85 for males (SD = 4.02) and 18.94 for females (SD = 3.07). Among male dance partners, 26 believed they had formed a strong friendship with their female partners and more considered them as close relatives (5) and lovers (17) compared to the females (22, 4, 15). However, 26 female dance partners felt they had strictly cooperative partnerships with their male counterparts, a sentiment shared by 19 male dance partners.

Materials

Expressive ties quality

The Expressive Ties in the Partnership Scale-DanceSport Couples (PS-DSC) was adopted for the current research (Liu and Wang, 2022; Liu et al., 2023). The questionnaire consists of 4 items, namely "In dance training or competition, I and my partner were full of passion," "I get along with my partner," "I and my partner appreciate each other," "I and my partner care about each other" and Cronbach α was 0.924. Confirmatory factor analysis (CFA) was conducted to examine the validity of the measurement.

Athlete engagement

Athlete Engagement Questionnaire (AEQ) (Lonsdale et al., 2007a,b) was adopted for our study. The good adaptability of the questionnaire among Chinese athletes has been verified (Wang et al., 2014; Ye, 2014; Ye et al., 2016). The scale consists of sixteen items, and Cronbach α was 0.943, and its' four dimensions Cronbach α was 0.867, 0.884, 0.910, 0.841, respectively.

Competitive performance

Performance includes satisfaction of it and competition field performance, so the Competitive Performance Questionnaire was with 4 items in total. (1) Athlete Satisfaction Questionnaire (ASQ) (Riemer and Chelladurai, 1998) was adopted. (2) the ranking, which was ordinal variable, in the competition was the performance outcomes, so it was assigned to a 5-level Likert scale according to 5 international-level DanceSport judges, the results obtained after data processing of five levels of ordinal variables with continuous variables were not biased. The scale consists of 4 items, and Cronbach α was 0.702. Confirmatory factor analysis (CFA) was conducted to examine the validity of the measurement. The fit indices were: $\chi^2/df = 0.042$, $NFI = 0.999$, $AGFI = 0.998$, $PNFI = 0.333$, $RMSEA = 0.000$, $SRMR = 0.005$.

Analysis strategy

We utilized SPSS 22.0 and Mplus 8.3 for data processing and analysis. To begin with, we performed a descriptive statistical analysis to calculate the mean, standard deviation, and correlation of all variables in order to gain insights into the characteristics of variables and their interrelationships. Subsequently, following the process outlined by Davis et al. (2013), we implemented the actor and partner interdependence model to scrutinize the reciprocal impact of one's expressive ties with their partner on their own competitive performance, as well as that of their partner's (Kenny et al., 2006). This statistical method, suitable for dyadic data analysis, has been extensively used in intimate-relationship studies (Campbell and Kashy, 2002). More specifically, the actor effect relates to the influence of an individual's characteristics on their own outcome variables, while the partner effect pertains to the impact of an individual's variables on their partner's outcome variables. Additionally, before analyzing the actor-partner effects, we will test the hypothesized model using the following indices: χ^2, df, CFI, TLI, RMSEA, SRMR. If the conditions of CFI > 0.9, TLI > 0.9, RMSEA<0.08, and SRMR<0.08 (Hu and Bentler, 1999) are satisfied, the model would be considered acceptable.

Results

Table 1 illustrates that for both genders, competitive performance is significantly linked not only with one's own perception of the quality of expressive ties but also with one's partner's perceived quality of expressive ties. More strikingly, the correlation coefficients for the quality of expressive ties in females and the competitive performance of males (r = 0.376, $p < 0.01$) exceeded those for the quality of expressive ties in males and the competitive performance of females (r = 0.393, $p < 0.01$). The scores of athlete engagement for both females and males showed a positive correlation with their respective competitive performances.

Moreover, we employed the Actor-Partner Interdependence Model (APIM) to analyze the mutual influence between the quality of expressive ties and competitive performance, moderated by the level of athlete engagement. Initially, to decrease covariance for a clearer understanding of the intercept before establishing the APIM, each independent variable needed to undergo a central transformation. This transformation was achieved by subtracting the score of expressive ties and athlete engagement from the overall sample mean of that variable (He et al., 2018). In order to verify the actor-partner effect of paired competitors' own expressive ties on their own or their partner's competitive performance, this study utilized the expressive ties between the couples as independent variables in Mplus, and their competitive performance as the dependent variables for model testing.

In Figure 3, the actor-partner effect model of athlete dyads' expressive ties on competitive performance was a saturated model ($\chi^2 = 0$, $df = 0$ and the parameters to be estimated in the model were exactly equal to the elements in the covariance matrix) which means that the model was just identified and has a perfect fit. In this case, the model fit index was no longer reported and only the path coefficients need to be focused on (Li et al., 2019).

As shown in Table 2, regarding the actor effects, male's perceived expressive ties quality ($\beta = 0.292$, $p = 0.012$) and the female's ($\beta = 0.443$, $p < 0.001$) will influence their own competitive performance. Regarding the partner effects, female's perceived expressive ties quality exerts influence on male's competitive performance ($\beta = 0.266$, $p = 0.023$). However, male's perceived expressive ties quality cannot influence female's competitive performance ($\beta = 0.102$, $p = 0.374$). So, hypothesis H1, H2, H4 were supported by our study, but H3 was unsupported.

Then, we add the athlete engagement as the mediator in the model, the mediating effect was analyzed using the bootstrap method, and 5,000 Bootstrap runs were performed, and the mediating effect was significant if the 95% CI did not contain 0. Figure 4 showed the mediating model, Table 3 showed the fitting index of the model. The model was perfect.

As shown in Figure 4, male's perceived expressive ties quality will influence his own athlete engagement ($\beta = 0.423$, $p < 0.001$) and female's athlete engagement ($\beta = 0.356$, $p = 0.006$). Female's perceived expressive ties quality has marginal significant effect on her own athlete engagement ($\beta = 0.270$, $p = 0.076$), and will influence male's athlete engagement ($\beta = 0.253$, $p = 0.011$). Male's athlete engagement level will influence his own competitive performance ($\beta = 0.339$, $p = 0.005$), female's athlete engagement level will influence her own competitive performance ($\beta = 0.428$, $p = 0.002$).

As shown in Table 4, regarding the actor effects, male' athlete engagement partially mediated the effect of his own perceived expressive ties quality on his own competitive performance [indirect effect = 0.144, *SE* = 0.072,95% confidence intervals (*CI*) = 0.020, 0.283]. However, female' athlete engagement cannot mediate the effect of her own perceived expressive ties quality on her own competitive performance [indirect effect = 0.152, *SE* = 0.069,95% confidence intervals (*CI*) = −0.004,0.168]. Regarding the partner effects, male' athlete engagement partially mediated the effect of female's perceived expressive ties quality on male's competitive performance [indirect effect = 0.086, *SE* = 0.041, 95% confidence intervals (*CI*) = 0.003, 0.149]. in addition, female' athlete engagement partially mediated the effect of male's perceived expressive ties quality on female's competitive performance [indirect effect = 0.152, *SE* = 0.074,95% confidence intervals (*CI*) = 0.002, 0.256]. the H5, H7, H8 were supported by our study, but H6 was unsupported.

Discussion

Actor effect analysis

Our results indicates that male's **(H1)** and female's **(H2)** perceived expressive ties quality affects their own competitive

TABLE 1 Mean, standard deviation, and correlation matrix of each research variable.

	M	SD	1	2	3	4	5	6
1. Expressive ties (M)	15.87	3.40	1					
2. Athlete Engagement (M)	70.40	9.69	0.454***	1				
3. Competitive performance (M)	12.19	3.59	0.393**	0.440***	1			
4. Expressive ties (F)	14.67	4.06	0.378**	0.266*	0.376**	1		
5. Athlete Engagement (F)	66.85	9.94	0.458**	0.281*	0.303*	0.448***	1	
6. Competitive performance (F)	12.00	2.88	0.269*	0.230	0.517***	0.482***	0.473***	1

*, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$. $N = 134$ couples; F, female; M, male.

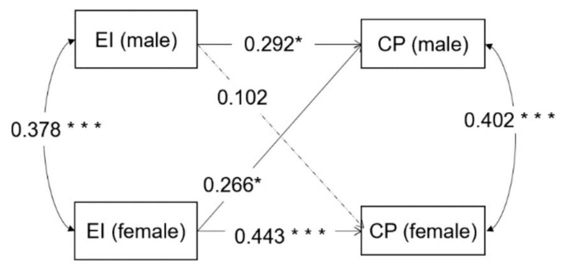

FIGURE 3
The actor-partner effect model of athlete dyads' expressive ties on competitive performance.

TABLE 2 Standardization path coefficient and hypothesis testing results of expressive ties' impact on competitive performance.

Effect	Path	β	t	p	Test results
Actor effect	ET (M) → CP (M)	0.292	2.498	0.012	H1: supported
Actor effect	ET (F) → CP(F)	0.443	3.854	<0.000	H2: supported
Partner effect	ET (M) → CP (F)	0.102	0.889	0.374	H3: unsupported
Partner effect	ET (F) → CP (M)	0.266	2.276	0.023	H4: supported

ET, expressive ties; CP, competitive performance; F, female; M, male.

performance, and male's athlete engagement partially mediates the effect of his own perceived expressive ties quality on his own competitive performance **(H5)**. These findings demonstrates that expressive ties between DanceSport partners and athlete engagement are critical factors influencing individuals' competitive performance. The findings of this study align coherently with the principles of Self-Determination Theory (SDT), as introduced in the context of the associated applied research. Partners engaging in nascent relational dynamics have been shown to exhibit increased levels of oxytocin (Moll et al., 2010), a biochemical change that can extend into the athletic milieu, potentially yielding a positive influence on performance (Campbell et al., 2016). Furthermore, Campbell et al. (2016) assert that while expressive relational ties can have beneficial spillover effects that enhance athletic outcomes, concomitant negative ramifications are plausible as per Reis and Aron (2008). Specifically, early-stage romantic involvements may be fraught with elements such as jealousy or conflict, precipitating fluctuations in mood, and episodes of anxiety and depression among partners. The spectrum of these emotional disturbances, irrespective of their perceived severity, holds the capacity to directly compromise an athlete's performance. However, for the present study, the dancers tend to be more in a cooperative relationship, with the referee scoring for dance dyads rather than one of them. Perhaps it is precisely because of this that dancers will feel happy rather than jealous and make appointments due to the progress of their partners, thus generating an actor effect, making highly expressive ties positively affect the dancer' competitive performance.

However, our results show that female' athlete engagement cannot mediate the effect of her own perceived expressive ties quality on her own competitive performance **(H6)**, which is inconsistent with the general interpersonal interaction (Kandel, 1978). The reasons may be as following:

(1) There is a threshold for female's athlete engagement to be activated to frame a mediating path between expressive ties and competitive performance, but the level of expressive ties quality that exists in and out of the arena from females to males is not sufficient to activate female's athlete engagement. On one hand, physiological load on females are more intensity than on males. For example, A study simulating competition situation found that, based on the characteristics of special holding technology in the modern dance, the HR_{sim}/HR_{max} and VO_{2hold}/VO_{2max} of males was significantly lower than that of females ($p < 0.01$), and pointed out that the oxygen consumption of females was 78% of that of male ($p < 0.05$), and the heart rate would increase by 14% ($p < 0.05$) when maintaining holding posture (Vaczi et al., 2016). According to sports physiology, overcoming the physiological load means that females need to have more positive psychological characteristics, and athlete engagement is the psychological characteristic required in sports, especially among elite athletes. We believe that, to a certain extent, females need to complete the competition through more confident, enthusiastic, and other positive high-level elements of athlete engagement. On the other hand, Females are more introverted and tend to avoid intimacy (Guo, 2016). Influenced by the traditional Chinese cultural, based on the gender theory, females will not express their hot thoughts too much. For example, in our study, while some males assess their female partners as lovers, females only perceived the existence of a cooperative relationship with them.

(2) Females' athlete engagement (e.g., passion and confidence) may not be strong predictors of their own competitive performance. Although females' technical movements in the arena are fuller of desire and are more likely to infect the audience and judges according to common sense, however, an empirical study proves that the passion of males will influence judges and audiences, while females' passion cannot (Yang, 2016). This is in line with the gender theory, gender segregation and stratification are worldwide phenomena, although more women have entered traditionally male occupations, so gender stratification will decrease. However, the road to the top of the professional level is not always smooth. Although not all females are excluded, they find it difficult to pass the middle tier in the professional field. The common and in-depth phenomenon that females blocked on the way forward is called glass ceiling: females can see her goals, but they will hit an obstacle that is invisible and cannot be passed through. In a survey of deputy directors of female cooperation, 71% of people said that their organizations have glass ceilings for females. However, 73% of male directors in the unified organization believed that this did not exist. This may be, as Williams and Best believed in a 1982 study in 30 countries, that

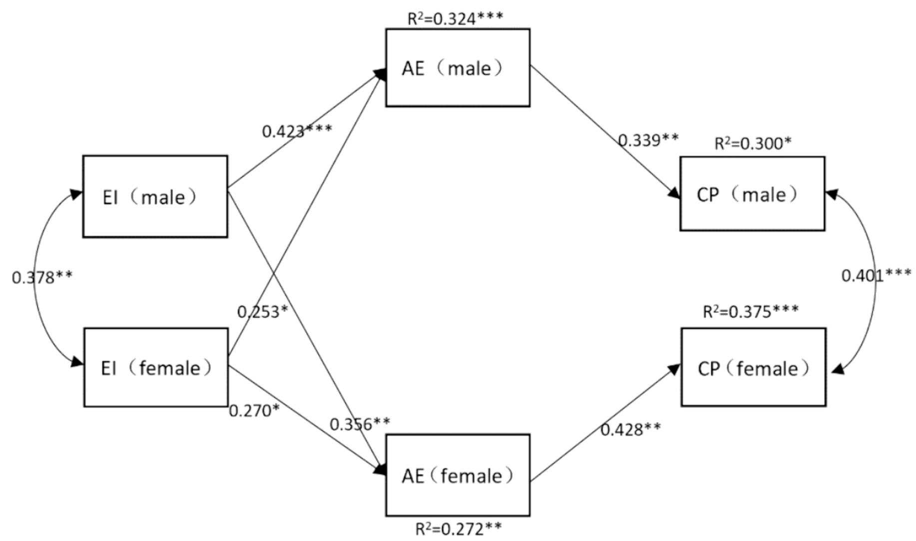

FIGURE 4
The mediating model highlighting the influence of expressive ties on competitive performance.

TABLE 3 Intermediate model fitting of dance partnership expressive ties on competitive performance.

	χ^2	*df*	CFI	TLI	RMSEA	SRMR
AE	115.934	14	1.000	1.020	0.000	0.017

gender stereotypes had been formed before the age of five, which developed rapidly in early school years and completed fully in adolescence, so many people were not aware of their existence (Crawford and Unger, 2009, pp. 677–680).

Partner effect analysis

Our results show that female's perceived expressive ties quality affects male's competitive performance **(H4)**; male' athlete engagement partially mediates the effect of female's perceived expressive ties quality on male's competitive performance **(H8)**. This finding demonstrates that male's athlete engagement is an important mediator. And this finding is in line with the ideas mentioned by SDT which states that athlete engagement put great influence in competitive performance, and also be verified by scholars that males may have a sense of unity and dominance with females after being infected by their enthusiasm, vitality and other athlete engagement characteristics (Lin, 2008), which means that the males were more passionate, and as Majoross et al. (2008) stated that the males' passion will have a critical impact on the judges and the audiences. To be more specific, according to Strathern (1996), dancers' physical expression needs to consider gender values, gender settings of DanceSport, etc. On one hand, the dualistic framework of gender roles (a dualistic concept called "*yin*" and "*yang*" in Chinese philosophy) cast the gender characteristics of strong males and weak females (Lin, 2008). On the other hand, because male dominance and female obedience occupies the core of western romantic impression and modern dating stereotype (Crawford and Unger, 2009, pp. 174), therefore, the technical characteristics of DanceSport require males to guide and females to follow. The dominant position of male requires them to conduct image training on the venue and dance before the competition. They imagine themselves to be strong and tough and expect themselves and their partners to regard each other as their lovers, thus creating a sense of unity. Even after finishing the dance competition, males feel that they are a proud lion who won the competition (Lin, 2008).

In addition, female's athlete engagement partially mediates the association between male's perceived expressive ties quality and female's competitive performance **(H7)**. It may be that the males' perceived expressive ties quality (e.g., care, appreciation, and passion) stimulates the females' athlete engagement and reaches a certain threshold, which would help predict the females' competitive performance. Specifically, after sharing the experience of weal and woe with females, males form a high perceived expressive ties quality. As shown by the matching characteristics of dance partners in our study, the average value of males in the expressive ties is 15.87, which is higher than the average value of females (14.67). When females have not recognized the relationship between them as a couple, males believe that they have reached a romantic relationship with females. This means that males have stronger emotions such as long-term care, appreciation, as well as stronger passion on the competition context. This can help males strengthen their self-concept, generate a state of confidence, vitality, and enthusiasm, and be more confident to succeed with their partners. Confidence is an important connotation of engagement, and is one of the most important abilities for high-level athletes to achieve successful performance (Platonov, 2014).

In addition, the contradiction between the results of H8 and H7 is that high expressive ties in males may not promote females' competitive performance, for males tend to perform worse in expressive ties, this may be detrimental to the emotional satisfaction of female Dance partners (Niedźwieńska and Zielińska, 2020), and according to self-determination theory, this may also result in high

TABLE 4 Significance test results of bootstrap mediation effect of expressive ties on competitive performance.

Path	Effect value	Bootstrap SE	95% Bootstrap CI	Test results
ET(M) → AE(M) → CP(M)	0.144	0.072	[0.020, 0.283]	H5: supported
ET(F) → AE(F) → CP(F)	0.115	0.069	[−0.004,0.168]	H6: unsupported
ET(M) → AE(F) → CP(F)	0.152	0.074	[0.002, 0.256]	H7: supported
ET(F) → AE(M) → CP(M)	0.086	0.041	[0.003, 0.149]	H8: supported

ET, expressive ties; AE, athlete engagement; CP, competitive performance; F, female; M, male.

expressive ties in males not promoting female dance partners' competitive performance and athlete engagement. Further empirical research is needed to verify whether this result can be extended to DanceSport couples.

Our study also finds that male's perceived expressive ties quality cannot affect female's competitive performance (**H3**), which does not conform to Donohue et al. (2007)'s viewpoint, that is supportive relationships help bolster performance. The reason may be as following: males are more confident and open as mentioned above, which make them overestimate their perceived expressive ties quality, thus making it difficult to predict the female's competitive performance. Especially attitude is heightened in Latin dances, this is no place for the timid, especially for male dancers, whose manner must be confident to the point of domination (John, 1998, pp. 40). In addition, based on gender stereotypes, males have a deep-rooted sense of dominance, and their level of self-confidence and work engagement is higher than that of females (Ackerman et al., 2011). A survey of Canadian public officials proves this view (Rabinowitz and Hall, 1977). So, it is not surprising, in our study, that males believe that females are their girlfriends on the premise that females do not recognize the intimate relationship between them. This more "aggressive" tendency may lead to a miscalculation of the current training or competition situation.

Conclusion

The findings of this study not only affirm the assertions of the Self-Determination Theory (SDT), but significantly contribute to its enrichment and enhancement. In particular, this calls for the SDT to consider individual gender characteristics. Specifically, (1) fulfillment of related sense or athlete engagement impacts performance output. Our research showed that males' and females' perceived expressive ties quality cast an actor effect on their own competitive performance, and male athlete engagement partially intervened in the correlation between his perceived expressive ties quality and his performance. Moreover, females' perceived expressive ties quality project a partner effect on males' performance, with male athlete engagement partially intervening in this correlation, and female athlete engagement partially intervening in the effect of male's perceived expressive ties quality on female's performance. (2) Over satisfaction of self-related sense or athlete engagement does not necessarily enhance performance output because males' perceived expressive ties quality, influenced by gender role traits imposed by Chinese cultural traditions and competitive sports culture, might intensify athlete engagement to a point resulting in misjudgment of current training or competition situations, and possibly fail to objectively promote female partners' performance, hence, our study shows male's perceived expressive ties quality has no significant impact on female's performance. Furthermore, female athlete engagement did not mediate the effect of her own perceived expressive ties quality on her performance, potentially because a threshold exists for female athlete engagement to facilitate a role in their own competitive performance, or due to biases in the DanceSport scoring system. Hence, we propose that both genders should foster their own as well as their partner's athlete engagement, which mediates the influence of expressive ties on competitive performance. Males should work diligently towards enhancing female partners' athlete engagement (e.g., elevating confidence and passion), while females should also take initiatives to develop their engagement. Simultaneously, males need to establish expressive contact with females more objectively.

Strengths and limitations

This study is framed by its strengths and limitations. The two noteworthy strengths are: (1) By embracing the essence of DanceSport, a dance form that revolves around love, gender (Ericksen, 2011, p. xii), and a romantic fantasia (Harman, 2019), we assume that the dynamics between DanceSport pairs significantly influences competitive outcomes. Our study explores this through the novel actor–partner interdependence mediation model to comprehend the mechanics of mixed-gender cooperation on performance, emphasizing male and female dancers' mutual influences. Earlier investigations have rarely scrutinized these dynamics, and even when considering paired sporting activities, the dominant focus is either related to athletic performance or sustains a descriptive account of observations on how partnering impacts results. (2) The conclusions of this study add robustness to the scientific aspects of the Self-Determination Theory (SDT), and contribute to its development by bringing individual gender attributes into focus, a significant aspect for the comprehensive evolution of SDT.

Nonetheless, the embryonic nature of our study brings forth two limitations: (1) Our sample is exclusively drawn from Chinese dance pairs, which limits the global generalizability of our findings. It would be beneficial for further research to engage broader samples from different countries. (2) In addition, the sample size warrants expansion. Although similar studies have been conducted with less than 67 pairs (e.g., Jackson et al., 2010 with 58 pairs, Habeeb et al., 2017 with 51 pairs) statistical errors are potential risks. For future studies, enlarging the sample size is an important consideration. Although expanding the sample size beyond 240 is challenging due to the constraints of competitions and performance information, along with the need to control the impact of variables such as referees, lighting, and venue, it is important for future research to consider.

Future research directions

Recognizing the cultural fabric woven into interpersonal interactions, future research needs to investigate the cultural context of dance partnerships (as unique relationships), delve deeper into their mutual influences, and perpetually enhance the theoretical frame of dance partnerships and competitive performance. In particular, Hsu (1953) suggests an exploration of interpersonal relationships within certain contexts. Furthermore, aligning with the epistemological strategy of cultural psychology, which echoes with the concept of "one mind, many meanings; disunified universalism" (Shweder et al., 1998, pp. 871; Hwang, 2018), and incorporating available studies on DanceSport partnerships and dance partner interaction practices, it becomes evident that DanceSport partnerships exhibit cultural identities (Liu et al., 2023). Thus, it becomes essential to thoroughly examine the backdrop of how dance partnerships impact competitive performance.

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 the Institutional Review Board of Nanchang University. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements.

Author contributions

XL: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. YL: Writing – review & editing. DP: Writing – review & editing. XW: 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.

Publisher's note

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The association between team behaviors and competitive anxiety among team-handball players: the mediating role of achievement goals

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Team sports athletes may encounter significant stress, leading to competitive anxiety. The anxiety levels can be influenced by team behaviors and achievement goals. This study aims to investigate the relationship between team behaviors (i.e., perceptions of controlling coaching behavior and team cohesion) and competitive anxiety, and to examine the mediation effects of achievement goals (i.e., task-oriented and ego-oriented) on the relationship. A total of 298 team-handball players were involved in the study, ages ranging from 16 to 24 years old ($M = 18.44$, SD = 3.09). A cross-sectional research design was adopted, and structural equation modeling was utilized to analyze path coefficients and mediating effects. Findings indicated that perceptions of controlling coaching behaviors had significant positive predictions for state and somatic anxiety ($\beta = 0.22$, 0.29) and negative predictions for self-confidence ($\beta = -0.19$). Team cohesion had significant negative predictions for state anxiety ($\beta = -0.31$) and positive predictions for self-confidence ($\beta = 0.58$). In addition, ego-oriented goals play a positive mediating role in the relationship between team behaviors and competitive anxiety ($\beta = 0.03-0.35$), while task-oriented goals play a negative mediating role in the relationship between team behaviors and competitive anxiety ($\beta = -0.18$ - -0.03). In conclusion, team behaviors have a significant relationship with competitive anxiety, with achievement goals playing a mediating role among them. Therefore, to alleviate team sports athletes' competitive anxiety, it is recommended to reduce coach control behaviors, enhance team cohesion, and employ psychological training methods (e.g., mindfulness or meditation) to strengthen athletes' task-oriented goals.

KEYWORDS

team behavior, controlling coaching behavior, team cohesion, achievement goals, competitive anxiety

Introduction

In competitive sports, athletes often encounter various psychological pressures, arising from the competition itself, expectations from coaches and the team, the scrutiny of the audience and the public, as well as the stress associated with injuries and health concerns, both before and during competitions. These potential pressures and threats can result in competitive anxiety, ultimately affecting their athletic performance and mental well-being (Craft et al., 2003; Woodman and Hardy, 2003).

In this field, cognitive motivational relational theory by Lazarus (2000) emphasizes the importance of cognition and goals in generating emotions, providing a potentially fruitful theoretical framework for investigating anxiety within competitive contexts. The theory posits that goals act as crucial mediators between cognitive appraisal (appraising the situation or behaviors) and emotional responses (e.g., anxiety) (Lazarus, 2000; Uphill and Jones, 2007). For example, during competitions, athletes' performance can be influenced by how they interpret their coach's feedback. If team sports athletes perceive the coach's reprimand as hindering their goal of winning, it may induce feelings of discouragement and anxiety, impacting their performance negatively. However, if they view the feedback as constructive criticism aimed at improvement, it can motivate them to make necessary adjustments and strive for better results.

In team sports, team behaviors (i.e., the behaviors of coaches and teammates) significantly influence the emotional states of athletes, particularly competitive anxiety. Coaching behaviors, especially controlling ones, may cause athletes to excessively focus on the game's outcome, creating a threatening environment (e.g., fear of failure and lack of recognition), thus increasing competitive anxiety (Ramis et al., 2017). Additionally, teammate behaviors, such as team cohesion, play a crucial role in helping athletes cultivate a more positive mindset (Craft et al., 2003). This contributes to boosting the self-confidence of athletes, enabling them to more effectively cope with competitive pressure and, as a result, alleviate competitive anxiety (Craft et al., 2003; Oh and Gill, 2017). Based on current empirical research, the majority of studies confirm that coach controlling behaviors positively predict athletes' competitive anxiety (Ramis et al., 2017; Cho et al., 2019), while team cohesion negatively predicts competitive anxiety (Oh and Gill, 2017; Najafi et al., 2018). However, there are still some studies indicating a lack of significant correlation between coach controlling behaviors and competitive anxiety (Vealey et al., 1998; Madson, 2021), as well as between team cohesion and competitive anxiety (Anderson, 2015; Haddera, 2015). Therefore, one of the purposes of this research was to further examine the relationship between team behaviors and competitive anxiety.

According to the achievement goal theory (Dweck, 1986), individual achievement goals can be divided into task-oriented and ego-oriented. Task-oriented athletes focus on self-learning and skill improvement, and this learning goal orientation helps alleviate competitive anxiety. Conversely, athletes holding primarily ego-oriented motivation excessively focus on the outcome of the competition, thereby increasing the likelihood of competitive anxiety. Furthermore, team behavior appears to be capable of altering athletes' competitive anxiety states by influencing their goal orientation. The controlling style of coaching behavior can reinforce ego-oriented goals in athletes through excessive supervision, guidance, and decision-making (Syrmpas and Bekiari, 2018), potentially leading to an increased level of competitive anxiety. Conversely, team cohesion, which emphasizes cooperation and shared goals, helps foster the task orientation of athletes, reducing excessive focus on competition outcomes and alleviating competitive anxiety (Prapavessis and Carron, 1996). Therefore, based on achievement goal theory and cognitive motivational relational theory, achievement goals mediate the relationship between team behavior (e.g., perceptions of controlling coaching behavior and team cohesion) and competitive anxiety. Current empirical research indicated a negative correlation between ego-oriented goals and positive coaching behavior or team cohesion, while a positive correlation existed between task-oriented goals and positive coaching behavior or team cohesion among team-handball players (Balaguer et al., 2002; Horn et al., 2012). Furthermore, ego-oriented goals were positively associated with competitive anxiety, whereas task-oriented goals showed a negative correlation with competitive anxiety among team-handball players (Abrahamsen et al., 2008; Duica et al., 2014). Despite theoretical and practical indications that achievement goals might mediate between team behavior and physical activity, there is a lack of comprehensive research investigating the mediating role of achievement goals in the relationship between team behavior and competitive anxiety. Hence, another objective of this study was to examine the mediating effect of achievement goals on the relationship between team behavior and competitive anxiety.

In summary, existing research indicates an inconsistent relationship between team behavior and competitive anxiety, with no conclusive evidence indicating that achievement goals play a mediating role between team behavior and competitive anxiety. Therefore, the primary aim of this study is to examine the correlation between team behavior (i.e., perceptions of controlling coaching behavior and team cohesion), achievement goals (i.e., task-oriented and ego-oriented), and competitive anxiety. Furthermore, the study aims to examine the potential mediating effect of achievement goals on the relationship between team behavior and competitive anxiety.

Materials and methods

Participants

A total of 298 team-handball players (76 males and 222 females) from three provincial clubs in the Shandong, Jiangsu, and Beijing regions of China participated in the study. Employing a randomized approach, three clubs were randomly selected from the pool of teams participating in each regional league. The sample size of 298 participants meets the minimum required sample size for structural equation modeling analysis, which was calculated as 119 using G-Power ($\alpha = 0.05$, power = 0.95). The participants were categorized into three age groups: U17 (15 to <17 years), U19 (17 to <19 years), and Senior group ($\geq$ 19 years). Informed consent was obtained from all participants or their legal guardians if under 18 years of age. Regarding training experience, over 89.3% of participants reported having three or more years of training experience. Additionally, the participants' sports levels ranged from amateur to elite. Specific characteristic details can be found in Table 1.

Measures

In this research, the respondents were requested to fill out a questionnaire that included demographic information (sex, age, training experience and sports level), Controlling Coach Behaviors Scale (CCBS) (Bartholomew et al., 2010), Group Environment Questionnaire (GEQ) (Ma, 2004), Task and Ego Orientation in Sports Questionnaire (TEOSQ) (Whitehead and Duda, 1998), and Competitive State Anxiety Inventory-2 (CSAI-2) (Martens et al., 1990). To ensure internal validity, the scales were adapted and validated within the Chinese cultural context, incorporating feedback from an expert panel, and conducting internal consistency checks

TABLE 1 General characteristics of the participants ($n = 298$).

Characteristics	Category	Frequency	Percentage
Gender	Male	76	25.5%
	Female	222	74.5%
Age group	U17	109	36.6%
	U19	119	39.9%
	Senior	70	23.5%
Training experience	1–2 years	32	10.7%
	3–4 years	157	52.7%
	≥ 5 years	109	36.6%
Sports level	Amateur	114	38.3%
	Sub-elite	114	38.3%
	Elite	70	23.4%

U17, 15 to < 17 years; U19, 17 to < 19 years; Senior, ≥ 19 years.

concurrently (Cronbach's alpha values >0.7) (Diotaiuti et al., 2017; Taber, 2018).

Controlling coaching behaviors

The CCBS (Bartholomew et al., 2010) was used to measure team-handball players' perceptions of controlling coaching behaviors. The CCBS scale encompasses four subscales with a total of 15 items: controlling use of rewards (e.g., "the only reason my coach rewards/praises me is to make me train harder"), negative conditional regard (e.g., "my coach pays me less attention if I have displeased him/her"), excessive personal control (e.g., "my coach tries to control what I do during my free time), and judging and devaluing (e.g., "my coach is very judgmental if I am not competing well"). A 5-point Likert scale, scored from 1 to 5, was used for responses. Higher scores indicate a stronger perception of controlling coaching behaviors. In this study, the internal consistency results for the four subscales indicate an acceptable reliability, with Cronbach's alpha values ranging from 0.77 to 0.91.

Team cohesion

The GEQ (Harter and Connell, 1984) was used to measure team cohesion among team-handball athletes. Ma (2004) adapted the GEQ based on the cultural attributes of Chinese team-handball athletes. This adapted questionnaire consists of four dimensions (15 items): group task attraction (e.g., "I'm pleased with the competitive drive in our team"), group social attraction (e.g., "I'm willing to participate in the team's social activities"), group task integration (e.g., "Our team is united in striving to achieve our goals."), and group social integration (e.g., "Our team members often gather together for social events"). The internal consistency results for the four subscales demonstrate an acceptable reliability in this sample (Cronbach's alpha, $\alpha = 0.68–0.91$).

Achievement goals

The TEOSQ (Whitehead and Duda, 1998) is a widely utilized instrument in the field of sports to evaluate athletes' achievement goals, specifically in terms of their task orientation and ego orientation. In this study, this scale was used to measure athletes' achievement motivation. The TEOSQ questionnaire comprises a total of 13 items, with 7 items designed to measure task orientation (e.g., motivation focused on self-improvement, personal mastery of skills, and achieving specific goals) and an additional 6 items intended to assess ego orientation (e.g., motivation driven by the pursuit of victory, seeking recognition, and competing with others). The internal consistency results for this scale demonstrate acceptable reliability (Cronbach's alpha, $\alpha = 0.89–0.93$).

Competitive anxiety

The CSAI-2 (Martens et al., 1990) was used to measure the competitive anxiety levels of team-handball athletes. Zhu (1993) adapted the CSAI-2 based on the characteristics of Chinese athletes and demonstrated the scale's strong reliability and validity. This adapted scale is comprised of three subscales: state anxiety (e.g., "I'm worried about this upcoming match"), somatic anxiety (e.g., "I feel tense physically"), and self-confidence (e.g., "I'm confident about this match"), with each subscale containing 9 items, making a total of 27 items. In this study, the internal consistency results for three dimensions indicate an acceptable reliability (Cronbach's alpha, $\alpha = 0.88–0.93$).

Procedures and research design

Permission for the athlete's survey was obtained from the Provincial Sports Bureau and the coaches. Before conducting this survey, all respondents were informed about the purpose of the study. All responses were anonymous, and participation was voluntary. Data was collected in September 2023. All structured questionnaires were distributed to the team-handball payers before a training session and collected on-site 20 min later, ensuring that no external interference occurred during that time to avoid any bias or influence. Among the 307 athletes invited to participate in this survey, 9 did not complete the test (the response rate was 97.1%). This survey followed the guidelines outlined in the Declaration of Helsinki (World Medical Association, 2013). The ethical approval and consent procedures for this study were approved by the Ludong University Ethics Committee (LDU-IRB202311002).

Statistical analysis

Descriptive statistics and correlations analysis were performed by using Statistical Package of the Social Sciences (IBM SPSS Statistics, version 25.0). Demographic characteristics, perceptions of controlling coaching behaviors, team cohesion, achievement goals, and competitive anxiety underwent descriptive statistics analysis, including the calculation of means, standard deviations, and percentages. Structural equation modeling (SEM) was conducted using Analysis of Moment Structures (AMOS, version 24.0). Confirmatory factor analysis (CFA) was utilized to assess the fitness of the model for each construct. The bootstrap method was used for mediation effect analysis (Parameters: bootstrap samples, 2000; PC confidence intervals, 95; BC confidence intervals, 95). To evaluate the overall model fit, the following fit indices were considered: Comparative Fit Index (CFI), Tucker–Lewis Index (TLI), Goodness of Fit Index (GFI), Normed Fit Index (NFI), Root Mean-Square Error of Approximation (RMSEA), and the likelihood ratio ($\chi 2/df$). The following criteria indicated an adequate model fit: RMSEA ≤ 0.08, $\chi 2/df < 5$, and other indices (CFI, TLI, GFI, and NFI) ≥ 0.9 (Heck and Thomas, 2020; Kline, 2023).

Results

Descriptive statistics

Table 2 shows the means, standard deviations, and correlations among competitive anxiety (i.e., somatic anxiety, state anxiety, and confidence), achievement goals, team cohesion, and perceptions of controlling coaching behaviors. Notably, perceptions of controlling coaching behaviors were positively associated with state anxiety, somatic anxiety, and task-oriented motivation, while exhibiting a negative correlation with self-confidence. Additionally, team cohesion was positively associated with self-confidence, task-oriented goals, and ego-oriented goals, while negatively associated with somatic anxiety. Furthermore, both task-oriented and ego-oriented goals displayed positive associations with self-confidence. In the realm of competitive anxiety, self-confidence exhibited a negative relationship with both somatic anxiety and state anxiety.

Structural equation modeling results

The structural equation modeling results are shown in Figure 1. In this structural model, perceptions of controlling coaching behaviors exhibited significant positive predictions for task-oriented and ego-oriented goals, state anxiety, and somatic anxiety ($\beta = 0.35$, 0.10, 0.22, 0.29, $p < 0.05$), while concurrently yielding negative predictions for self-confidence ($\beta = -0.19$, $p < 0.05$). Team cohesion emerged as a robust predictor, demonstrating significant positive associations with task-oriented and ego-oriented goals, as well as self-confidence ($\beta = 0.58$, 0.82, 0.28, $p < 0.05$), while showing a negative prediction for state anxiety ($\beta = -0.31$, $p < 0.05$). Moreover, the task-oriented goal displayed a significant positive prediction for self-confidence ($\beta = 0.17$, $p < 0.05$), and a simultaneous negative prediction for somatic anxiety ($\beta = -0.20$, $p < 0.05$). Additionally, the ego-oriented goal showed a significant positive prediction for state anxiety and somatic anxiety ($\beta = 0.38$, 0.24, $p < 0.05$).

Table 3 illustrates the Bootstrap mediation effects of achievement goals (i.e., task-oriented and ego-oriented) serving as mediators in the relationship between coaching behaviors and competitive anxiety, as well as in the relationship between team cohesion and competitive anxiety. The findings indicated that ego-oriented goals mediated between perceptions of controlling coaching behavior and state anxiety, as well as between perceptions of controlling coaching behavior and somatic anxiety. Additionally, ego-oriented goals served as a mediator between team cohesion and both state anxiety and somatic anxiety. However, there was no mediating effect of ego-oriented goal observed between perceptions of controlling coaching behaviors and self-confidence, nor between team cohesion and self-confidence. On the other hand, the mediating role of task-oriented goals was evident in the relationship between perceptions of controlling coaching behavior and somatic anxiety.

Discussion

This study aimed to explore the relationship between team behaviors, achievement goals, and competitive anxiety. Specifically, it aimed to test the mediating role of achievement goals (task-oriented and ego-oriented) in the relationship between team behaviors and competitive anxiety. The results of this study found that perceptions of controlling coaching behavior positively predicted somatic and state anxiety, and negatively predicted self-confidence. Team cohesion positively predicted self-confidence and negatively predicted state anxiety. Additionally, ego-oriented goals positively predicted competitive anxiety, while task-oriented goals negatively predicted competitive anxiety. Although several mediating pathways were not significant, overall, team behaviors positively predicted competitive anxiety through the mediating role of ego-oriented goals and negatively predicted competitive anxiety through the mediating role of task-oriented goals.

Our findings suggested a significant positive correlation between coaches' controlling behavior and competitive anxiety among team-handball players. This implies that higher levels of coach control may lead to increased competitive anxiety, which is consistent with previous studies. Ramis et al. (2017) found that coaches' controlling style could result in increased competitive anxiety, including somatic anxiety, worry, and concentration disruption, among athletes participating in various team sports. Similarly, Cho et al. (2019) demonstrated that controlling coaching behavior increased competitive trait anxiety among collegiate athletes. Controlling coaching behaviors through coercion, pressure, and authoritarianism establishes an atmosphere where athletes experience the pressure to perform according to the coach's demands, leading to somatic symptoms and cognitive difficulties in focusing on the competitive situation (Cho et al., 2019). Additionally, negative emotions triggered by controlling coaching behavior could contribute to a decline in athletes' self-confidence levels, a finding corroborated by the results of this study. This aligns with the research by Pesidas and Serrano (2023), which also supported the notion that detrimental controlling coaching behaviors could undermine the self-confidence of athletes. However, it's crucial to acknowledge the study by (Vealey et al., 1998), which did not find a significant predictive effect of perceived coaching behavior on competitive anxiety. The primary reason for this disparity is attributed to the use of a comprehensive scale that did not differentiate between controlling and supportive coaching behaviors, potentially accounting for the differences in results. Therefore, for coaches, they should reduce controlling behaviors and appropriately increase supportive behaviors to alleviate athletes' competitive anxiety and enhance their athletic performance.

This study also demonstrated that team cohesion had a significant predictive effect on improving athlete self-confidence and mitigating cognitive anxiety. This aligns with previous research (Prapavessis and Carron, 1996; Haddera, 2015), which indicated that athletes with higher team cohesion levels often experience lower levels of competitive anxiety and possess higher levels of self-confidence. Team cohesion plays a pivotal role in cultivating a positive psychological environment by offering emotional support, bolstering collective efficacy through a shared commitment to achieving team goals, fostering a positive and collaborative atmosphere, and building a trusting internal environment (Carron et al., 2002; Ramzaninezhad et al., 2009). Consequently, this contributes to the strengthening of collective identity, ultimately boosting athlete self-confidence and alleviating cognitive anxiety. However, Haddera (2015) found no significant associations between team cohesion and competitive anxiety among female basketball players. This may be attributed to factors such as societal expectations, cultural attitudes towards

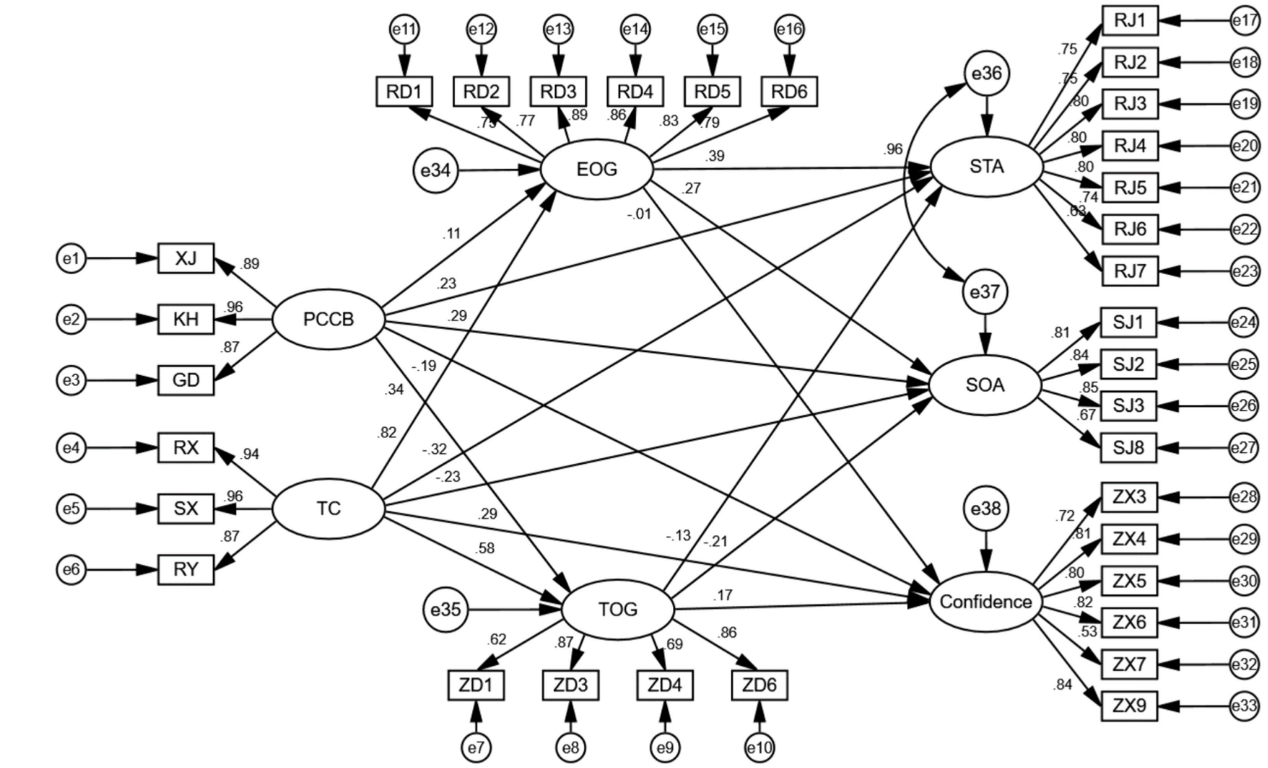

FIGURE 1
Structural equation modeling results. Note: EOG, ego-oriented goal; PCCB, perceptions of controlling coaching behavior; SOA, somatic anxiety; STA, state anxiety; TOG, task-oriented goal. This model has an acceptable fit (χ^2/df = 2.912; CFI = 0.921; TLI = 0.907; IFI = 0.922; GFI = 0.831). With the exception of the paths EOG → Confidence, TOG → STA, and TC → SOA, all other paths were significant at $p < 0.05$ level.

TABLE 2 Means, standard deviations, and correlations.

Variables	1	2	3	4	5	6	7
1. STA	1						
2. SOA	0.96***	1.00					
3. Confidence	−0.21**	−0.20**	1				
4. TOG	0.03	−0.07	0.27***	1			
5. EOG	0.05	−0.05	0.34***	0.73***	1		
6. PCCB	0.23***	0.26***	−0.16*	0.29***	0.04	1	
7. TC	−0.09	−0.15*	0.39***	0.54***	0.81***	−0.08	1
Mean	2.52	2.18	2.75	4.19	3.80	2.61	4.08
SD	0.73	0.68	0.60	0.67	0.82	0.87	0.58

EOG, ego-oriented goal; PCCB, perceptions of controlling coaching behavior; SOA, somatic anxiety; STA, state anxiety; TC, team cohesion; TOG, task-oriented goal. Confidence, SOA and STA are the subscales of competitive anxiety. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

women in sports, and gender-specific social support, potentially weakening the predictive impact of team cohesion on competitive anxiety. Therefore, enhancing team cohesion may contribute to creating a supportive and favorable environment, thus potentially bolstering athletes' self-confidence and reducing competitive anxiety. However, it's important to note that the relationship between team cohesion and competitive anxiety may vary across different contexts and populations.

Interestingly, the study found that overall, task-oriented goals played a negative mediating role between team behavior and competitive anxiety, while ego-directed goals played a positive mediating role between team behavior and competitive anxiety. This means that task-oriented goals may weaken the positive relationship between team cohesion and competitive anxiety, thereby helping to reduce competitive anxiety among team athletes. Conversely, ego-oriented goals may strengthen this relationship, thereby increasing the level of competitive anxiety among team athletes. This finding aligns with the research by Duica et al. (2014), who found that ego-oriented goals significantly positively predicted cognitive and somatic anxiety in elite team-handball and team-volleyball athletes,

TABLE 3 Bootstrap mediation effects of achievement goals in the relationship between team cohesion and competitive anxiety, as well as perceptions of controlling coaching behavior and competitive anxiety.

Effect	Path	Beta		95% CI	
			P	Lower	Upper
Direct effect	PCCB → STA	0.161	**	0.052	0.293
Indirect effect	PCCB → EOG → STA	0.031	**	0.006	0.077
Indirect effect	PCCB → TOG → STA	−0.03	0.312	−0.094	0.031
Total effect	PCCB → STA	0.162	**	0.064	0.275
Direct effect	PCCB → SOA	0.273	***	0.142	0.440
Indirect effect	PCCB → EOG → SOA	0.029	*	0.001	0.080
Indirect effect	PCCB → TOG → SOA	−0.068	*	−0.149	−0.001
Total effect	PCCB → SOA	0.233	***	0.114	0.385
Direct effect	PCCB → SC	−0.148	*	−0.267	−0.030
Indirect effect	PCCB → EOG → SC	−0.001	0.945	−0.029	0.027
Indirect effect	PCCB → TOG → SC	0.047	0.177	−0.025	0.119
Total effect	PCCB → SC	−0.102	*	−0.206	−0.002
Direct effect	TC → STA	−0.347	*	−0.607	−0.049
Indirect effect	TC → EOG → STA	0.351	*	0.082	0.622
Indirect effect	TC → TOG → STA	−0.080	0.323	−0.246	0.087
Total effect	TC → STA	−0.076	0.375	−0.251	0.072
Direct effect	TC → SOA	−0.333	0.114	−0.688	0.091
Indirect effect	TC → EOG → SOA	0.323	*	0.000	0.654
Indirect effect	TC → TOG → SOA	−0.181	0.072	−0.366	0.016
Total effect	TC → SOA	−0.191	0.080	−0.428	0.027
Direct effect	TC → SC	0.359	*	0.057	0.706
Indirect effect	TC → EOG → SC	−0.008	0.967	−0.314	0.286
Indirect effect	TC → TOG → SC	0.125	0.185	−0.070	0.313
Total effect	TC → SC	0.476	***	0.336	0.636

EOG, ego-oriented goal; PCCB, perceptions of controlling coaching behavior; SOA, somatic anxiety; SC, self-confidence; STA, state anxiety; TC, team cohesion; TOG, task-oriented goal. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

whereas task-oriented goals had a significant negative predictive effect on cognitive and somatic anxiety. Typically, team athletes with a task-oriented focus prioritize understanding, gaining knowledge, and improving their competence and ability, which helps reduce the impact of external adverse factors (e.g., negative coaching behavior and excessive public expectations) on competitive anxiety (Brdar et al., 2006). In contrast, ego-oriented athletes prioritize positive evaluations from others, rendering them more susceptible to external influences (Tian et al., 2017). This heightened susceptibility exacerbates the state of competitive anxiety in athletes, as evidenced in the context of our study. Similarly, the study by Abrahamsen et al. (2008) also found team-handball players with task-oriented goals exhibit lower levels of competitive anxiety. However, it is noteworthy that the findings of this study regarding the predicting effect of team behaviors on achievement goals are inconsistent with the findings with Syrmpas and Bekiari (2018). The study by Syrmpas and Bekiari (2018) suggested a closer association between negative coaching behavior and ego-oriented goals compared to task-oriented goals, in contrast to the results of this study. This may be attributed to differences in sample characteristics (e.g., age, skill level, and cultural background). Therefore, it seems that adjusting coaching behavior to regulate the goal orientation of athletes is not an effective method. It is recommended to explore alternative approaches, such as mindfulness or meditation training, to foster a task-oriented focus among athletes and thereby alleviate competitive anxiety. Finally, for coaches, practitioners, and sports psychologists, it is advised to take more specific measures, such as integrating goal-setting strategies or mindfulness interventions to help athletes cultivate task-oriented goals, thus better managing competitive anxiety.

Although our study provides substantial insights into the relationship between team behavior, achievement goals, and competitive anxiety, it is important to acknowledge certain limitations. Firstly, a cross-sectional design was applied in this research. However, the cross-sectional design is limited in providing a clear depiction of the temporal changes in variables and causal relationships. This limitation may hinder the understanding of the dynamic relationships among team behaviors, achievement goals, and competitive anxiety. Future research should employ longitudinal designs to track changes in these variables over time and ascertain causal relationships more accurately. Secondly, the use of convenience sampling in this study limited the generalizability. Convenience sampling often fails to represent the target population adequately, potentially compromising the broader applicability of the results. Future studies should employ more rigorous probability sampling techniques to ensure a more representative sample and enhance the external validity of the findings. Thirdly, given the limited size of the sample and its diversity in terms of age and sport levels, caution is necessary in interpreting the results. The findings may be more applicable to adolescents and amateur or sub-elite populations. Fourthly, the data for this study was collected through self-report methods, particularly regarding perceptions of controlling coaching behavior. Despite using anonymous questionnaires, response biases such as social desirability bias may have influenced the results. This could have resulted in an incomplete portrayal of the true sentiments and experiences of team-handball players. To mitigate this issue, future research could consider incorporating objective measurement methods, such as behavioral observation or physiological measures, to provide more comprehensive and objective data.

Conclusion

The results supported the notion that the perceptions of controlling coaching behavior, team cohesion, and achievement goals were of importance to understanding competitive anxiety in team-handball players. Greater levels of controlling coaching behavior may predict higher levels of athletic anxiety, while increased team cohesion may predict lower levels of competitive anxiety. Additionally, task-oriented goals negatively mediate the relationship between team behavior and competitive anxiety, whereas ego-directed goals positively mediate this relationship. Hence, enhancing team cohesion, reducing controlling coaching behavior, and emphasizing task-oriented goals appear to be effective strategies for alleviating competitive anxiety. However, to ensure the credibility of these conclusions, intervention studies are needed for further validation.

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 Ludong University 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

XW: Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. ZS: Writing – review & editing, Supervision. LY: Conceptualization, Writing – original editing, Data curation. DepD: Writing – review & editing, Project administration, Methodology, Funding acquisition. DelD: Writing – original draft, Methodology, Data curation.

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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

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Jumping with control: the interplay between psychological constructs and run-up variability in elite jumpers

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Objectives: The purpose of this study was to examine the relationship between psychological aspects (emotional regulation, self-control, mood states, and perceived stress) and components of run-up variability in horizontal jumps and to conduct comparisons based on sex, events (long jump and triple jump), and contextual situations (training versus competition).

Methods: A total of 10 elite-level athletes (five males and five females) with a mean age of 27.14 (±4.25) years were recruited for the study. All participants had competed nationally or internationally and had 13.10 (±3.48) years of athletic experience. Data were collected during competitions and training sessions for 5 weeks. The participants completed the Brunel Mood Scale, Emotional Regulation Questionnaire, Brief Self-Control Scale, and Visual Analogical Scale of Perceived Stress before each session. The components of run-up variability of successful and failed attempts were measured using video analysis. Data were analyzed using a t-test, Pearson's correlation, and Cohen's d.

Results: Athletes specializing in long jump and triple jump displayed similar psychological and run-up variability characteristics. However, females showed higher values for tension and depression, whereas males had higher run-up speeds and vigor. In competitions, athletes tended to have higher vigor, lower fatigue and confusion, an earlier beginning of the adjustment phase, fewer failed attempts, and higher run-up speed than during training. Emotional regulation is inversely related to depression in women during competitions, whereas higher self-control is associated with fewer failed jumps.

Conclusion: Athletes competing in the long jump and the triple jump do not differ in psychological traits and run-up characteristics, which suggests that similar training strategies can be used in both events. However, different solutions should be used considering the sex of athletes, with a particular focus on utilizing emotion regulation tools to modulate depression in female jumpers. It is recommended to include training sessions that simulate competition demands, primarily to ensure the early onset of the run-up adjustment phase.

KEYWORDS

athletics, long jump, triple jump, run-up variability, emotional regulation, selfcontrol

1 Introduction

Long and triple jumps are two of the most demanding events in track and field, requiring speed, power, and technique. Success in these events heavily depends on the ability to execute a consistent and effective run-up, which is crucial for athletes to hit the board accurately and achieve the optimal speed and proper position to jump (Hay, 1998). However, run-up, which comprises programmed acceleration and adjustment phases, is also one of the most challenging aspects of these events, and even slight variations in speed or step length can significantly impact performance. Inconsistencies in step lengths during the run-up accumulate due to factors such as wind, surface type, and the athlete's physical condition. Although athletes train to adjust the length of the last steps considering these factors, many failed attempts continue to occur (Wu et al., 2013).

Failed jumps can affect performance because they can alter the running pattern of subsequent attempts (McCosker et al., 2019), increase anxiety levels, and decrease confidence, impairing the athlete's ability to execute the jump properly. The variability in run-up has been extensively studied owing to its biomechanical aspects and visual regulation (Lee et al., 1982; Hay, 1993; Scott et al., 1997; Panteli et al., 2011; Theodorou et al., 2011; Panteli et al., 2014; Makaruk et al., 2015; Panteli et al., 2015; Starzak et al., 2016). It has been shown that run-up variability follows a standard pattern, with inconsistencies accumulating during the acceleration phase and corrections beginning approximately five steps before the take-off board (Hay, 1993). Makaruk et al. (2015) found that the earlier adjustments to step length are made, the greater the speed conserved at take-off. However, these factors alone do not explain the individual strategies employed by athletes during competition (McCosker et al., 2021).

The visual system significantly influences a jumper's performance as it is linked to the perception-action system (Miller and Clapp, 2011). However, athletes with low vision (category F13) regulated their step length in the same manner as sighted athletes, albeit with limited visual information (Theodorou et al., 2011). An experiment with F11 category athletes yielded equivalent results (Theodorou and Skordilis, 2012), suggesting that the ability to adjust the final steps to hit the board can also be influenced by kinesthetic or auditory feedback.

More experienced athletes have superior perceptual abilities and information processing capacity (Panteli et al., 2014), which may explain their better performance than less experienced athletes. Visual regulation influences run-up variability (Hay, 1998; Bradshaw and Aisbett, 2006; Panteli et al., 2011, 2014), although visual control has not been measured objectively in many studies. In Hildebrandt and Cañal-Bruland (2020) compared measures of visual regulation based on locomotion, as in the traditional method, with measures based on visualization among athletes wearing special glasses. They found that the beginning of visual regulation, determined by the locomotion method, coincided with the step where the longest gaze toward the take-off board was observed, but not with the step of the first visualization. Despite this pioneering study, the scarcity of objective measures calls attention to other aspects that may influence run-ups in horizontal jumps.

Despite the number of studies investigating the biomechanical aspects and visual regulation of run-ups, few have examined the psychological factors that may affect performance, highlighting an essential gap in our understanding of run-up variability. Scott et al. (1997), for example, found that the need to make valid attempts is one of the factors that affects run-up, suggesting that anxiety in training and competition contexts can influence its variability. Lee et al. (1982) also reported that run-up variability could be affected by factors such as confidence, fatigue, and wind. McCosker et al. asserted that the environment of horizontal jumping events is a complex system with different intervening variables, including psychological (McCosker et al., 2019) variables, that must be studied.

A recent study proposed that elite jumpers must adapt their actions to the competition's physical and emotional demands (McCosker et al., 2021). Horizontal jumps are perceived as a series of connected events, and athletes must employ self-regulation strategies to achieve their performance goals. When considering the manifestations of psychological constructs during sports practice, it has been suggested that individuals seek to experience emotions that bring them closer to their goals, regardless of the pleasure or displeasure that these emotions may arouse (Tamir, 2009). Nonetheless, positive emotions such as happiness and excitement benefit concentration and performance (Vast et al., 2010), and emotional regulation strategies can be used to induce these states.

Emotional regulation plays a crucial role in an athlete's performance by affecting their movement, reaction time, range of motion, and force production (Beatty et al., 2014). To optimize performance, athletes use emotional regulation strategies such as relaxation, attention redirection, self-talk, and imagery, which help create the best possible emotional climate (Lane et al., 2011, 2012). Among these strategies, self-talk is effective in improving concentration and performance, and has been used in preparation by international and Olympic athletes (Balague, 2000; Gould et al., 2001, 2005; Blumenstein and Lidor, 2007; Scala et al., 2018). Through emotional regulation, athletes can modify the intensity of their emotions to direct them toward desired levels.

Another aspect that has received significant attention from researchers is mood states. Mood and emotion are part of the same conceptual model, and a clear distinction between them is not always possible (Lane and Terry, 2000). In addition, mood and emotion are evaluated in the same manner, which makes their differentiation challenging. Therefore, this study uses both terms interchangeably. Mood states can be interpreted by constructing profiles that consider normalized values (percentiles) for the following six factors: tension, depression, anger, vigor, fatigue, and confusion. Six mood state profiles were identified: iceberg, inverted iceberg, inverted Everest, fin, surface, and submerged (Parsons-Smith et al., 2017). The same six clusters were found in a study of Brazilian athletes (Brandão et al., 2021).

Emotions and stress are related. Stress is a psychological state comprising emotional and cognitive responses that interfere with the performance of a target behavior (Rosenbaum, 1989). Stress does not reside in the individual or environment but in the relationship between the two; it is not necessarily debilitating and can even facilitate performance (Hanton et al., 2005). Thus, the "directional perception" of stress sources, that is, the individual interpretation of these sources regarding their positive or negative effects, assumes importance (Brandão et al., 2021). Elevated levels of perceived stress can increase competitive anxiety in athletes and potentially worsen their performance (Hammermeister and Burton, 2001). This finding suggests the need to understand the emotions and stress experienced by athletes at different times of competition and their effects on sports performance. In general, athletes perceive that with an increase in the importance of competition, the pressure for performance also increases, generating a great stress load that needs to be managed (Hanton et al., 2005).

Self-control is essential for managing stressful situations. Self-control is an individual's ability to overcome impulses, temptations, and desires (Hagger, 2013; Englert, 2016) and regulate thoughts and behaviors to achieve long-term goals (Allom et al., 2016). Studies have shown that athletes have higher levels of self-control than the general population (Toering and Jordet, 2015), and individuals with higher levels of self-control perform better in sports tasks where hitting a target is required (Bresin et al., 2012), suggesting that self-control can be trained (Muraven, 2010) and can be an essential psychological characteristic for horizontal jumpers who need to hit the board.

Evidently, sports performance is multifactorial, involving physical components (biological and biomechanical), emotional aspects (psychological and psychosocial), and learning elements (technical and tactical) (Brandão and Figueira Junior, 1996). Therefore, connections between these distinct aspects must be studied (Figure 1).

This study investigated the relationship between psychological factors (emotional regulation, self-control, mood states, and perceived stress) and elements contributing to run-up variability in horizontal jumps. Additionally, this study aimed to conduct comparisons based on sex, events (long jump and triple jump), and contextual situations (training versus competition).

We hypothesized that individuals with elevated self-control and emotional regulation levels would demonstrate enhanced speed, reduced run-up variability, and an earlier onset of the adjustment phase. Conversely, individuals experiencing negative mood states and elevated stress levels were predicted to exhibit decreased speed and increased run-up variability. Furthermore, we anticipated that both events would share comparable psychological and run-up characteristics, whereas sex differences would manifest as distinct psychological traits. Additionally, we hypothesized that there would be significant disparities in psychological constructs and run-up variability between the training and competitive contexts.

2 Methods

2.1 Study design

This study is a quantitative and observational field research (Gil, 2002), submitted to the Ethics Committee in Research at São Judas University and approved under number CAAE: 40826120.6.0000.0089.

2.2 Participants

Ten athletes participated in the study: five males (height: 185.32 ± 6.22 cm; body mass: 81.60 ± 7.23 kg) and five females (height: 166.86 ± 6.72 cm; body mass: 58.20 ± 6.92 kg), with a mean age of 27.14 (±4.25) years, specialists in the long jump and triple jump. The athletes had 13.10 (±3.48) years of experience in athletics and the following mean of personal best results: 6.59 ± 0.21 m, $n = 2$ (female long jumpers); 7.91 ± 0.13 m, $n = 2$ (male long jumpers); 13.09 ± 1.09 m, $n = 3$ (female triple jumpers); and 16.85 ± 0.05 m, $n = 3$ (male triple jumpers). Participants were chosen for convenience and for standing

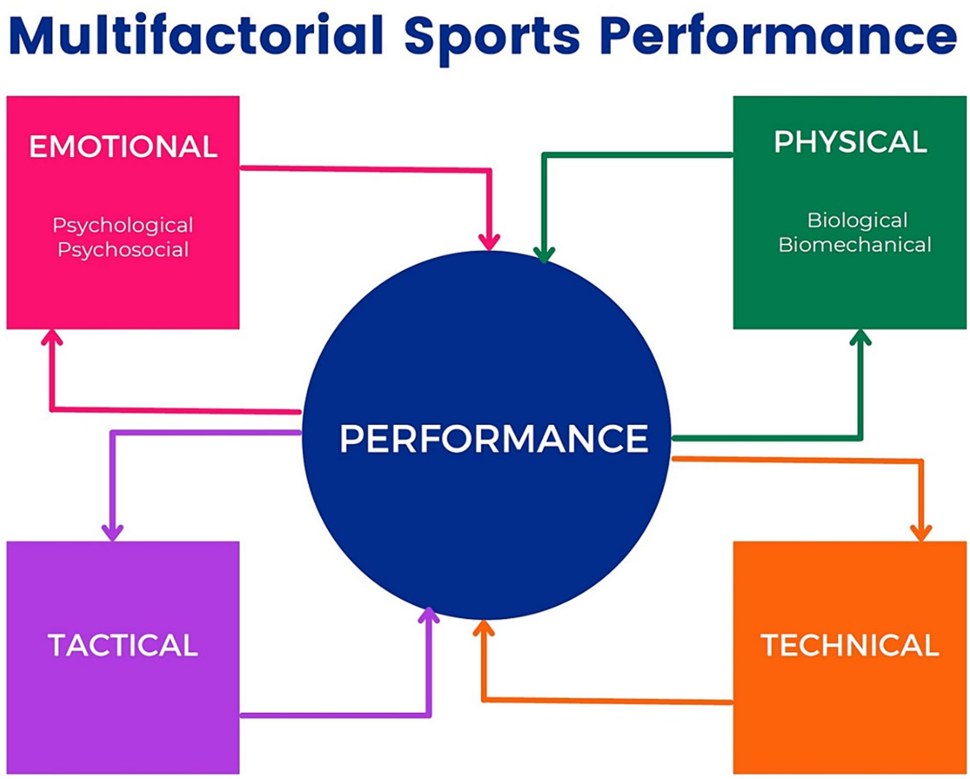

FIGURE 1
Multifactorial sports performance. Adapted from Brandão and Figueira Junior (1996).

out nationally (among the top ten in the national ranking or in the Brazilian championships in the previous year). Injured athletes who had been away from training and competitions for more than a month were excluded from the sample.

2.3 Instruments and procedures

Written informed consent was obtained from all participants, and the study procedures followed the Declaration of Helsinki guidelines. All steps were performed to ensure the athletes' anonymity and data confidentiality. However, due to the participants' characteristics, it was not possible to guarantee that they would not be identified. Training sessions and competitions were assessed during a 5-week competition block.

2.3.1 Psychological aspects

To assess psychological aspects (emotional regulation, self-control, mood states, and perceived stress), three questionnaires and a visual analog scale were used, which were answered before the start of training sessions and before warming up for competitions:

- Emotional Regulation Questionnaire (Gross and John, 2003), validated for athletes by Uphill et al. (2012) and for the Brazilian population by Gouveia et al. (2018).
- Brief Self-Control Scale (BSCS) (Tangney et al., 2004), validated for the Brazilian population by Figueira et al. (2019).
- Brunel Mood Scale (BRUMS), validated for Brazilian athletes by Rohlfs & Miranda (De Rohlfs and Miranda, 2006).
- Visual Analog Scale (VAS) for Stress: This instrument is a quick and simple tool for assessing stress levels, consisting of a horizontal line 10 cm long labeled at its ends with "minimal stress" and "maximal stress" (Guimarães, 1998; Gould et al., 2001). Athletes made a mark on the scale indicating how they perceived their level of negative stress at that moment. The distance from the start of the scale to this mark was measured using a ruler, and the value in centimeters represented the perceived level of stress (Figure 2).

The questionnaires were administered in small groups, separated by sex and event, while respecting training and competition schedules. The questionnaires were distributed 30 min before the start of training sessions and 90 min before the competitions to avoid interference with the warm-up and athletes' presentations before entering the track.

2.3.2 Run-up variability

Run-up variability was evaluated in two situations: during technical training sessions, where athletes performed run-ups followed by take-off without landing, and during official competitions. A total of 98 run-ups from four training sessions and 129 jumps from four competitions were analyzed. Each athlete participated in at least two data collection procedures for each condition.

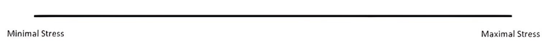

FIGURE 2
Visual analog scale (VAS) for stress.

2.3.2.1 Training sessions

The athletes performed four attempts with approximately 5 min of rest between them. The pre-training warm-up routine was the same as that the athletes used (jogging, dynamic stretching, running or jumping drills, and accelerations) and lasted approximately 30 min. Marks were made with adhesive tape on both sides of the runway at every meter for later analysis using Dartfish 10 Team ProData software (Dartfish, Fribourg, Switzerland). Jumps were recorded on HD video at 120 frames per second with a Sony FDR-AX53 camera (Sony Electronics Inc., San Jose, CA, USA), which was fixed on a tripod 20 meters from the jump runway, 7.5 meters before the takeoff board, eight meters above the level of the track (Figure 3). The average speed in the final segment of the run-up was evaluated by positioning two sets of Witty dual-beam photocells (Microgate, Bolzano, Italy) alongside the runway; one pair was positioned at 1 meter and the other at 6 meters before the take-off board.

The protocol for assessing run-up variability is commonly used in athletics. In a series of jumps or run-ups, the toe-to-board distance is measured along the entire run-up (Lee et al., 1982; McCosker et al., 2020) or a certain number of steps before take-off (Theodorou et al., 2013; Makaruk et al., 2015). For each event (training or competition), the standard deviation of this distance for each step is calculated, indicating the accumulated error in that step. Our study measured running variability in the last six steps (Moura et al., 2023).

2.3.2.2 Competition sessions

The same procedures as in the training sessions were followed, with the athletes performing three to six attempts at each competition.

For each training and competition event, the following parameters were used to evaluate the run-up variability:

- Distance lost at the board: the distance between the take-off point and the measuring line, with negative values indicating failed attempts.
- Percentage of failed attempts.
- The magnitude of the largest accumulated error: the highest standard deviation was found in the last six steps of the run-up.
- The adjustment onset: the step where the largest error was observed, representing the onset of the visual regulation and adjustment phases.
- Absolute adjustment: the difference between the largest accumulated error and the error observed on the board.
- Relative adjustment: the percentage difference between the largest accumulated error and the error observed on the board.
- Average approach speed.

2.4 Statistical analysis

Data analysis was performed using JASP 0.16.1 software (University of Amsterdam, Netherlands). The Shapiro–Wilk test indicated a normal distribution, and the mean and standard deviation were calculated. The independent samples t-test was used to compare sexes and events. Paired samples t-test was used to compare the competition and training situations. Additionally, effect size (ES) was calculated for all differences

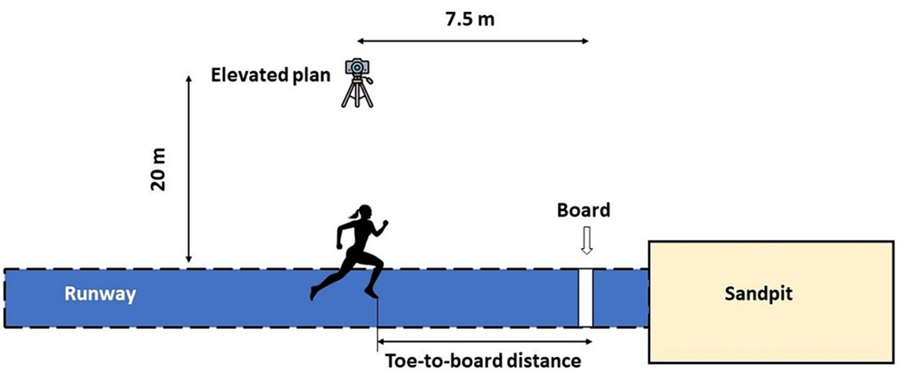

FIGURE 3
Procedures for measuring run-up variability. Adapted from Theodorou et al. (2013).

TABLE 1 Comparison of psychological constructs between events, across all situations, and both sexes.

	Long Jump Mean ± SD	Triple Jump Mean ± SD	*p*	ES
Self-control (score)	34.74 ± 5.28	33.78 ± 4.53	0.67	0.20
Stress (cm)	4.07 ± 1.98	3.04 ± 2.16	0.30	0.49
Emotional Regulation (score)	53.02 ± 5.68	46.00 ± 5.73	0.01**	1.23++
Tension (score)	3.43 ± 2.06	2.71 ± 2.63	0.52	0.30
Depression (score)	0.35 ± 0.35	0.47 ± 0.53	0.61	−0.24
Anger (score)	1.30 ± 1.87	1.22 ± 1.61	0.92	0.05
Vigor (score)	10.88 ± 2.70	10.57 ± 2.59	0.80	0.12
Fatigue (score)	2.57 ± 1.91	1.79 ± 1.86	0.38	0.42
Confusion (score)	1.36 ± 1.23	1.33 ± 1.91	0.97	0.02

**$p < 0.01$, ++ ES large.
ES, Effect size (Cohen's *d*).

using Cohen's *d*, with the following interpretation criteria: $d \leq 0.19$ = insignificant; $0.20 \leq d \leq 0.49$ = small; $0.50 \leq d \leq 0.79$ = medium; $0.80 \leq d \leq 1.29$ = large; $d \geq 1.30$ = very large (Espírito-Santo and Daniel, 2015). Relationships between variables were quantified using the Pearson's correlation coefficient. The significance level was set at $p < 0.05$.

3 Results

Athletes' *t*-tests for independent and paired samples were used to identify differences between events, situations, and sexes.

3.1 Comparisons between events

Table 1 presents the outcomes of independent samples t-tests comparing psychological constructs between the events in both training and competition, without considering the participants' sexes. Emotional regulation showed a significant difference ($p = 0.01$), with higher scores observed for the long jump.

Table 2 displays the results of independent samples t-tests comparing aspects of run-up variability between the events in training and competition without distinguishing by sex. No significant differences were found, although the long jump demonstrated higher values for speed with a medium effect size.

3.2 Comparisons between sexes

Table 3 shows the outcomes of the independent samples t-tests comparing psychological constructs between the sexes in both training and competition. Significant differences were found for tension ($p = 0.01$) and depression ($p < 0.001$), with females exhibiting higher values. Medium effect sizes were observed for stress, anger, and confusion, all of which were higher among females. Conversely, males displayed higher vigor scores with a medium effect size.

Table 4 shows the results of independent sample t-tests comparing aspects of run-up variability between the sexes in both training and competition. A significant difference was found for speed ($p < 0.001$), with males displaying greater values. Additionally, females showed higher losses on the board with a medium effect size.

3.3 Comparisons between training and competition

Table 5 displays the results of the paired samples *t*-tests comparing psychological constructs between training and competition. Significant differences were observed for vigor ($p = 0.01$), which was higher in competition, fatigue ($p < 0.001$), and confusion ($p = 0.02$), both of which were higher in training. Additionally, there was a medium effect size for anger, which was higher in training.

TABLE 2 Comparison of aspects of run-up variability between events, across all situations, and both sexes.

	Long Jump Mean ± SD	Triple Jump Mean ± SD	*p*	ES
Board losses (m)	0.03 ± 0.05	0.00 ± 0.10	0.42	0.38
Failed attempts (%)	50.16 ± 14.41	58.49 ± 22.89	0.37	−0.42
Speed (m/s)	9.55 ± 0.51	9.01 ± 0.80	0.11	0.77+
Largest error (m)	0.35 ± 0.09	0.40 ± 0.18	0.51	−0.31
Adjustment onset (n)	4.62 ± 0.91	4.21 ± 0.97	0.36	0.43
Absolute adjustment (m)	0.21 ± 0.05	0.21 ± 0.10	0.83	−0.10
Relative adjustment (%)	59.17 ± 8.02	55.87 ± 13.52	0.54	0.28

+ ES medium.
ES, effect size (Cohen's *d*).

TABLE 3 Comparison of psychological constructs between sexes in horizontal jumps, across all situations.

	Female Mean ± SD	Male Mean ± SD	*p*	ES
Self-control (score)	33.90 ± 2.88	34.42 ± 6.23	0.81	−0.11
Stress (cm)	4.17 ± 1.79	2.73 ± 2.23	0.13	0.72+
Emotional regulation (score)	50.00 ± 6.96	47.62 ± 6.33	0.43	0.36
Tension (score)	4.30 ± 2.43	1.69 ± 1.52	0.01**	1.29++
Depression (score)	0.75 ± 0.42	0.09 ± 0.18	<0.001***	2.02+++
Anger (score)	1.83 ± 2.01	0.68 ± 1.04	0.12	0.72+
Vigor (score)	9.80 ± 1.64	11.59 ± 3.08	0.12	−0.73+
Fatigue (score)	2.12 ± 1.78	2.09 ± 2.06	0.98	0.01
Confusion (score)	1.77 ± 1.96	0.93 ± 1.18	0.26	0.52+

**$p < 0.01$, ***$p < 0.001$, + ES medium, ++ ES large, +++ ES very large.
ES, effect size (Cohen's *d*).

TABLE 4 Comparison of aspects of run-up variability between sexes in horizontal jumps, across all situations.

	Female Mean ± SD	Male Mean ± SD	*p*	ES
Board losses (m)	0.04 ± 0.06	−0.01 ± 0.10	0.16	0.65+
Failed attempts (%)	52.86 ± 17.06	57.46 ± 23.16	0.62	−0.23
Speed (m/s)	8.60 ± 0.48	9.86 ± 0.17	< 0.001***	−3.51+++
Largest error (m)	0.36 ± 0.08	0.40 ± 0.20	0.64	−0.21
Adjustment onset (n)	4.53 ± 1.02	4.21 ± 0.88	0.46	0.34
Absolute adjustment (m)	0.20 ± 0.06	0.22 ± 0.10	0.70	−0.17
Relative adjustment (%)	56.39 ± 8.89	57.99 ± 14.10	0.76	−0.14

***$p < 0.001$, + ES medium, +++ ES very large.
ES, effect size (Cohen's *d*).

Table 6 presents the results of the paired *t*-test comparing aspects of run-up variability between training and competition. A significant difference was found for failed attempts ($p = 0.02$), which were higher in training. Furthermore, medium effect sizes were observed for board losses and speed, both of which were higher in competition.

3.4 Relationship between variables

The *t*-tests revealed non-significant differences across most psychological constructs and aspects of run-up variability when comparing the events, except emotional regulation. Therefore, all athletes were treated as participants in horizontal jumps for the correlation analysis, without distinguishing between specific events.

Significant differences were observed across more variables when comparing situations (training and competition) and sex (male and female). Therefore, separate analyses were conducted for different situations and sexes.

Correlation matrices were generated for each condition, highlighting significant relationships in bold. Table 7 shows the correlation matrix for female athletes during training, revealing statistically significant correlations between the eight pairs of variables.

Table 8 illustrates the correlation matrix for female athletes during the competition, demonstrating statistically significant correlations between the 11 pairs of variables.

TABLE 5 Comparison of psychological constructs between training and competition situations in horizontal jumps across both sexes.

	Training Mean ± SD	Competition Mean ± SD	*p*	ES
Self-control (score)	34.70 ± 4.84	33.63 ± 4.82	0.30	0.35
Stress (cm)	3.37 ± 1.97	3.53 ± 2.33	0.82	−0.08
Emotional Regulation (score)	48.77 ± 6.96	48.85 ± 6.57	0.94	−0.02
Tension (score)	2.62 ± 2.46	3.38 ± 2.38	0.27	−0.37
Depression (score)	0.48 ± 0.41	0.36 ± 0.52	0.43	0.26
Anger (score)	1.93 ± 2.02	0.57 ± 0.88	0.06	0.68+
Vigor (score)	9.72 ± 2.68	11.68 ± 2.15	0.01**	−1.02++
Fatigue (score)	3.18 ± 1.67	1.02 ± 1.42	< 0.001***	1.28++
Confusion (score)	1.82 ± 1.83	0.88 ± 1.34	0.02*	0.91++

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, + ES medium, ++ ES large.
ES, effect size (Cohen's *d*).

TABLE 6 Comparison of aspects of run-up variability between training and competition situations in horizontal jumps across both sexes.

	Training Mean ± SD	Competition Mean ± SD	*p*	ES
Board losses (m)	−0.02 ± 0.10	0.04 ± 0.04	0.07	−0.65+
Failed attempts (%)	66.53 ± 16.86	43.79 ± 16.35	0.02*	0.92++
Speed (m/s)	9.20 ± 0.77	9.26 ± 0.73	0.15	−0.50+
Largest error (m)	0.43 ± 0.18	0.33 ± 0.09	0.20	0.44
Adjustment onset (n)	4.47 ± 1.00	4.28 ± 0.93	0.52	0.21
Absolute adjustment (m)	0.23 ± 0.10	0.19 ± 0.05	0.32	0.33
Relative adjustment (%)	57.23 ± 14.90	57.15 ± 7.55	0.99	0.01

*$p < 0.05$, + ES medium, ++ ES large.
ES, effect size (Cohen's *d*).

Table 9 presents the correlation matrix for male athletes during training, identifying statistically significant correlations between the 11 pairs of variables.

Finally, Table 10 presents the correlation matrix for male athletes during competitions, revealing statistically significant correlations between the 13 pairs of variables.

4 Discussion

This study investigated the relationship between run-up variability in horizontal jumps and various psychological constructs, with comparisons based on sex, event type, and context (training versus competition). The findings indicate that the events were similar in terms of both technical and psychological aspects. However, significant differences emerged when comparing sexes and situational contexts. Negative mood states were interrelated, and female athletes who exhibited higher levels of emotional regulation experienced lower levels of depression. Additionally, higher levels of self-control were associated with fewer failed attempts.

4.1 Comparisons between events

When we compared the events, only emotional regulation showed a significant difference in favor of the long jump. This similarity was expected since these events are classified within the same subgroup called "horizontal jumps" in athletics (Hay, 1993), with performance being determined by similar factors such as approach speed (Moura et al., 2005b), special strength (Moura and de Paula Moura, 2001), and precision on the board (Hay and Koh, 1988). It is common to find athletes who participate with similar levels of success in both events. Although data were collected only for the main event in the studied group, various athletes competed in both the long and triple jumps. This justifies the analysis of the relationships between the variables, considering that all athletes integrated into the same group (horizontal jumps) without distinction regarding events. Despite this, the difference in speed, although not statistically significant, presented medium effect sizes, and this finding will be discussed below.

The run-up speed was higher in the long jump. It has long been discussed whether faster athletes are preferentially selected for the long jump or whether the characteristics of the triple jump event limit the possibility of using a larger portion of the maximum speed capacity (Hay, 1993). The relationship between approach speed and performance in both jumps is positive and significant. However, the correlation values are higher in the long jump (Moura et al., 2005a), suggesting a more significant number of determining factors in the triple jump (Hutt, 1989; Moura et al., 2023). Hay (1993) demonstrated that when studying athletes who participated in both events, approach speeds were higher in the long jump, which strengthens the understanding that it is the characteristics and demands of the events and not necessarily the athletes' abilities that are responsible for the reduced values of approach speed in the triple jump.

TABLE 7 Correlation matrix between psychological constructs and aspects of run-up variability in horizontal jumps for females, in training.

	Self-control	Stress	Emotional regulation	Tension	Depression	Anger	Vigor	Fatigue	Confusion	Board losses	Failed attempts	Speed	Largest error	Adjust. onset	Absolute adjustment	Relative adjustment
1. Self-control	—															
2. Stress	0.63	—														
3. Emotional regulation	−0.04	0.74	—													
4. Tension	0.73	0.43	−0.02	—												
5. Depression	−0.62	−0.58	−0.35	−0.73	—											
6. Anger	0.77	0.34	−0.21	0.95*	−0.53	—										
7. Vigor	0.36	0.26	−0.01	−0.36	0.05	−0.28	—									
8. Fatigue	0.85	0.61	0.11	0.97**	−0.81	0.91*	−0.16	—								
9. Confusion	0.94*	0.38	−0.28	0.61	−0.57	0.66	0.48	0.71	—							
10. Board losses	0.52	0.66	0.42	0.85	−0.62	0.76	−0.48	0.84	0.24	—						
11. Failed attempts	0.16	0.02	−0.18	−0.54	0.34	−0.40	0.95*	−0.38	0.31	−0.67	—					
12. Speed	−0.44	0.06	0.39	0.05	0.25	0.02	−0.76	−0.07	−0.71	0.46	−0.69	—				
13. Largest error	0.64	0.32	−0.01	0.43	−0.80	0.30	0.42	0.55	0.78	0.10	0.19	−0.77	—			
14. Adjustment onset	0.42	0.55	0.22	−0.19	0.22	−0.03	0.74	−0.01	0.31	−0.05	0.72	−0.20	−0.05	—		
15. Abs. adjustment	0.40	0.37	0.25	0.04	−0.64	−0.12	0.63	0.22	0.53	−0.13	0.41	−0.76	0.89*	0.12	—	
16. Relative adjustment	0.04	0.37	0.51	−0.37	−0.32	−0.53	0.68	−0.17	0.12	−0.32	0.53	−0.52	0.54	0.28	0.86	—

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

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TABLE 8 Correlation matrix between psychological constructs and aspects of run-up variability in horizontal jumps for females, in competition.

	Self-control	Stress	Emotional Regulation	Tension	Depression	Anger	Vigor	Fatigue	Confusion	Board losses	Failed attempts	Speed	Largest error	Adjust. onset	Absolute adjustment	Relative adjustment
1. Self-control	—															
2. Stress	0.31	—														
3. Emotional Regulation	0.45	−0.32	—													
4. Tension	0.18	0.68	−0.72	—												
5. Depression	−0.35	0.65	−0.90*	0.82	—											
6. Anger	0.11	0.86	−0.52	0.87	0.81	—										
7. Vigor	0.36	0.40	−0.45	0.45	0.32	0.15	—									
8. Fatigue	0.40	0.84	−0.23	0.79	0.56	0.94*	0.09	—								
9. Confusion	0.43	0.84	−0.31	0.85	0.60	0.94*	0.20	0.99**	—							
10. Board losses	0.00	0.32	−0.86	0.76	0.69	0.40	0.78	0.23	0.35	—						
11. Failed attempts	−0.87*	0.01	−0.43	0.07	0.52	0.29	−0.54	0.05	−0.01	−0.09	—					
12. Speed	−0.21	−0.96**	0.55	−0.84	−0.80	−0.92*	−0.48	−0.84	−0.87	−0.54	−0.08	—				
13. Largest error	−0.39	−0.51	−0.48	0.25	0.20	−0.06	−0.14	−0.18	−0.12	0.41	0.30	0.27	—			
14. Adjustment onset	−0.07	0.68	−0.08	0.39	0.49	0.79	−0.39	0.78	0.69	−0.22	0.53	−0.61	−0.30	—		
15. Abs. adjustment	0.01	−0.76	−0.04	−0.11	−0.35	−0.53	0.04	−0.49	−0.42	0.24	−0.27	0.60	0.78	−0.76	—	
16. Relative adjustment	0.45	0.12	0.69	−0.55	−0.57	−0.37	0.15	−0.20	−0.24	−0.49	−0.55	0.12	−0.89*	−0.12	−0.43	—

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

TABLE 9 Correlation matrix between psychological constructs and aspects of run-up variability in horizontal jumps for males, in training.

	Self-control	Stress	Emotional Regulation	Tension	Depression	Anger	Vigor	Fatigue	Confusion	Board losses	Failed attempts	Speed	Largest error	Adjust. onset	Absolute adjustment	Relative adjustment
1. Self-control	—															
2. Stress	−0.56	—														
3. Emotional Regulation	−0.45	0.37	—													
4. Tension	−0.34	0.79	0.76	—												
5. Depression	−0.01	0.69	0.62	0.93*	—											
6. Anger	−0.75	0.48	−0.06	−0.04	−0.21	—										
7. Vigor	−0.30	0.39	0.45	0.33	0.39	0.49	—									
8. Fatigue	−0.36	0.11	0.96**	0.57	0.43	−0.18	0.35	—								
9. Confusion	−0.39	0.57	0.92*	0.93*	0.80	−0.16	0.26	0.82	—							
10. Board losses	0.46	−0.55	0.44	0.07	0.16	−0.83	−0.15	0.61	0.34	—						
11. Failed attempts	−0.78	0.44	−0.20	−0.08	−0.34	0.87	0.02	−0.30	−0.18	−0.85	—					
12. Speed	−0.30	0.83	0.69	0.94*	0.94*	0.13	0.60	0.47	0.80	−0.06	−0.07	—				
13. Largest error	−0.42	−0.49	0.22	−0.41	−0.62	0.22	0.04	0.42	−0.10	0.24	0.21	−0.47	—			
14. Adjustment onset	−0.18	0.72	0.18	0.49	0.60	0.49	0.80	−0.05	0.22	−0.48	0.14	0.75	−0.51	—		
15. Abs. adjustment	−0.62	0.36	−0.30	−0.23	−0.36	0.97**	0.35	−0.40	−0.38	−0.90*	0.88*	−0.05	0.18	0.41	—	
16. Relative adjustment	−0.29	0.80	−0.22	0.32	0.33	0.61	0.29	−0.48	−0.02	−0.86	0.56	0.48	−0.63	0.76	0.62	—

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

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TABLE 10 Correlation matrix between psychological constructs and aspects of run-up variability in horizontal jumps for males, in competition.

	Self-control	Stress	Emotional regulation	Tension	Depression	Anger	Vigor	Fatigue	Confusion	Board losses	Failed attempts	Speed	Largest error	Adjust. onset	Absolute adjustment	Relative adjustment
1. Self-control	—															
2. Stress	−0.09	—														
3. Emotional Regulation	−0.46	0.41	—													
4. Tension	0.37	0.83	−0.10	—												
5. Depression	−0.20	−0.58	0.50	−0.84	—											
6. Anger	−0.31	0.88*	0.65	0.59	−0.29	—										
7. Vigor	0.04	0.05	0.07	−0.09	0.10	−0.27	—									
8. Fatigue	−0.16	0.95*	0.62	0.70	−0.35	0.97**	−0.10	—								
9. Confusion	0.01	0.96**	0.55	0.77	−0.39	0.88*	0.10	0.97**	—							
10. Board losses	0.95*	0.04	−0.54	0.49	−0.40	−0.30	0.26	−0.12	0.10	—						
11. Failed attempts	−0.25	−0.24	0.40	−0.57	0.63	−0.30	0.81	−0.23	−0.13	−0.18	—					
12. Speed	−0.27	0.84	0.82	0.43	−0.04	0.85	0.23	0.91*	0.91*	−0.21	0.20	—				
13. Largest error	0.54	0.46	−0.02	0.55	−0.33	0.06	0.72	0.29	0.53	0.72	0.28	0.39	—			
14. Adjustment onset	−0.52	0.70	0.78	0.21	0.03	0.69	0.44	0.73	0.73	−0.39	0.45	0.92*	0.33	—		
15. Abs. adjustment	0.57	0.49	0.10	0.55	−0.24	0.14	0.66	0.37	0.59	0.70	0.28	0.47	0.99**	0.37	—	
16. Relative adjustment	0.49	0.52	0.50	0.50	0.04	0.54	−0.05	0.64	0.71	0.38	−0.10	0.62	0.48	0.30	0.62	—

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

4.2 Comparisons between sexes

Significant differences were found between the sexes. Among psychological constructs, depression, and tension were higher among females. Additionally, medium effect sizes were found for confusion, stress and anger, which were higher in females, and vigor, which was higher in males. Differences in mood states between male and female athletes have been noted previously, and the same trends were verified in this study. Our results are similar to those found by Brandt et al. (2010) when studying Brazilian sailors, in which women had higher values of stress, depression, and anger, and lower vigor than men. In a study of 953 young Brazilian athletes, Brandão et al. (2021) found higher values for negative mood states, such as fatigue, confusion, and depression, among women, who also had a higher prevalence of the inverted iceberg and inverted Everest clusters. Han et al. (2021), when validating the Brunel Mood Scale in the cultural context of Singapore, found that mood scores varied predictably when participants were divided into distinct groups, particularly when separated by sex, where women had higher values for depression, anger, stress, fatigue, and confusion, and men hd higher vigor. A similar study among the Spanish population had comparable results, with women having higher scores for anger, depression, confusion, and fatigue and men having higher scores for vigor (Cañadas et al., 2017). Brandt et al. (2011) point to the psychophysiological characteristics of females to explain the higher levels of anger typically found among women. However, the possibility that these differences were partially caused by sociocultural factors cannot be ignored. Women were belatedly admitted into sports in the fight for equity that crossed the 20th century and is ongoing (Rubio and Veloso, 2019). This may increase demand beyond what is implicit within the sport, leading to fear of failure, perfectionism, and concerns about body image, among other factors (Killham et al., 2018), potentially altering mood states and emotions (Fox, 2008).

Regarding the components of run-up variability, speed was significantly higher among males, as expected. The average approach speed of female jumpers (8.60 ± 0.48 m/s) represented 87.22% of that of male jumpers (9.86 ± 0.17 m/s), a percentage similar to that observed in major international competitions. For example, analyzing the reports from the 2009 World Championships in Berlin, where average speeds measured in the same way as in our study were reported, men approached the board at 10.42 ± 0.21 m/s in their best trials in the long jump final and 10.05 ± 0.22 m/s in the triple jump final. However, women had speeds of 9.28 ± 0.32 m/s in the long jump final and 8.97 ± 0.22 m/s in the triple jump final, respectively 89.09 and 89.25% of the values presented by men (Mendoza et al., 2009a,b).

4.3 Comparisons between training and competition

Significant differences were observed between the training and competition situations. Among the psychological constructs, fatigue and confusion presented higher values in training, whereas vigor was higher in competition. Fatigue was expected to be lower on competition days, as this is a condition for achieving superior results. In the days leading up to the most important competitions, it is common to adopt tapering practices, in which the training load is substantially reduced to eliminate the effects of fatigue and allow for the expression of adaptations caused by training (Mujika, 2009). This procedure may also be related to increased vigor during competitions, which has been negatively associated with fatigue (Rohlfs et al., 2008). Prapavessis & Grove (Prapavessis and Grove, 1994) evaluated shooters at four-time points before the competition (from 48 h to 15 min before its start) and noticed an acute increase in vigor 15 min before the event. This study also found larger effect sizes for anger, during training. These differences seen together, moved in the desired direction, favoring the manifestation of the iceberg profile during competitions, a profile considered to facilitate performance (Lochbaum et al., 2021).

Among the aspects of run-up variability, there were significantly more failed attempts in training, as also noted by McCosker et al. (2020). Although this may be related to the absence of consequences for fouls in this situation, these authors believe that experienced athletes are able to use the information provided by the competition environment (for example, the position of the referee next to the take-off board) as an additional reference to adjust step lengths, information that is not available during training. Medium effect sizes were observed for losses on the board and speed, both higher in competitions, which may reinforce their importance for performance in competitions. Approach speed is considered a critical factor in determining jumping distance (Moura et al., 2005b). During competitions, athletes may be more motivated and in a heightened state of alertness, which can lead to an increase in run-up speed compared to training and, consequently, improved performance.

4.4 Relationship between variables

In general, among both sexes, during training and competition, negative mood states such as depression, tension, anger, fatigue, and confusion were related to each other and to stress. This finding confirms those of other authors studying the relationship between stress factors, dimensions of burnout syndrome, and negative mood states, with positive associations in all these aspects (Rinaldi, 2020).

It was expected that individuals with higher emotional regulation and self-control would better manage their mood states, as in Tamir et al.'s study (Tamir et al., 2008), where individuals used emotional regulation strategies to evoke the mood state that best fits the task at hand, but overall, this hypothesis was not confirmed in the present study. Nevertheless, females with higher emotional regulation in competition showed lower levels of depression, an important finding because this mood state tends to elevate the values of other negative states, modulating their deleterious influence on performance (Lane et al., 2005). In turn, self-control showed a strong relationship with losses on the board in competition for males (0.95, $p < 0.05$), which, considering the presented data, can be seen as positive, as it could decrease the number of failed attempts. In competition, the relationship between self-control and failed attempts among females was high (−0.87, $p = 0.05$), acting precisely in that direction. Findings from Bresin et al. (2012), who demonstrated that individuals with more self-control hit the target more accurately in computerized tasks, and Rosenbaum (1989), who suggested that coping with stress-generating situations, such as the need to produce valid jumps in competitions, requires self-control, support our results.

5 Limitations

Although it is a common characteristic in investigations of high-performance athletes, the small number of participants represents a limitation of our study, as it makes it difficult to generalize the conclusions and reduces the statistical power to identify differences where they really exist. Furthermore, in our experimental model, we used the traditional approach to study run-ups in horizontal jumps, where there is a growing variability in the first part of the run-up, followed by a decrease from six to four steps before the take-off board (Hay, 1993). Therefore, we measured variability only in the last six steps because this procedure allowed us to extract the most critical indicators. Recently, it was demonstrated that Australian international-level athletes have greater functional variability in the first part of the run-up and start visual regulation very early, up to 17 steps before the board, unlike national-level athletes, who would behave similarly to the traditional model (McCosker et al., 2020). Therefore, the fact that we did not evaluate the first part of the run-up constitutes a limitation of our study. Due to logistical constraints and to avoid interference with each athlete's preparation ritual, the evaluation of psychological constructs occurred a considerable amount of time before the start of the competitions (90 min), and there was no attempt to measure changes during the competition or training. The measurement of heart rate variability, whose parasympathetic variation is related to vigor (Leite et al., 2013), may help estimate mood changes during competition when researchers usually do not have contact with athletes, and it is possible to explore this in the future.

6 Conclusion

Long jump and triple jump exhibit comparable psychological and run-up variability characteristics. This similarity indicates that strategies for emotional regulation, speed, and run-up accuracy optimization may broadly apply across both events. However, notable differences were found between female and male jumpers in terms of their emotional states, implying that distinct strategies should be employed to promote optimal mood states during competitions, with a particular focus on utilizing emotional regulation tools to modulate depression among female jumpers.

The higher number of failed attempts in training suggests that the strategies used may not replicate the demands of the competition or effectively facilitate the desired changes as intended by coaches. Therefore, it is crucial to explore training run-up methods to simulate the competition's context and demands more closely.

The onset of competition adjustment is associated with increased losses on the board, which, in turn, inversely correlates with the number of failed attempts. If these losses remain within appropriate values, exploring the ability to initiate the adjustment phase early is essential.

Among the psychological constructs, self-control emerged as a significant factor associated with fewer failed attempts or greater losses on the board, both of which can contribute to a more successful performance. Hence, integrating techniques for developing self-control should be considered in the preparation of horizontal jumpers.

Although this study provides insights into the interplay between psychological constructs and run-up variability in horizontal jumps, there are still areas for further research to explore. Future investigations could consider the entire course of the run-up and the emotional changes that occur leading up to and during the competition. Such studies could enhance our understanding of the complex inter-relationships between psychological constructs and run-up variability during horizontal jumps. This study represents a preliminary step in this direction and contributes to the growing body of knowledge in this area.

7 Practical recommendations

- Incorporate Emotional Regulation Training: Develop training sessions that focus on emotional regulation techniques such as self-talk, relaxation, and visualization. These can help athletes manage stress and maintain optimal mood states.
- Simulate Competition Conditions in Training: Create training scenarios that mimic the pressures and conditions of competition. This can help athletes adapt their run-up strategies and reduce the number of failed attempts during actual competitions.
- Focus on Early Run-Up Adjustments: Encourage athletes to start their run-up adjustments earlier to maintain speed and improve accuracy at the take-off board. This approach can help reduce variability and increase performance consistency.
- Enhance Self-Control Skills: Implement exercises and routines aimed at improving self-control, which has been linked to fewer failed jumps. Techniques may include goal setting, impulse control exercises, and mental rehearsal.
- Tailored Training Based on Sex Differences: Recognize and address the distinct psychological needs of male and female athletes. For instance, additional support for emotional regulation may be necessary for female athletes to manage higher levels of depression and tension.

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 Ethics Committee in Research at São Judas University and approved under number CAAE: 40826120.6.0000.0089. 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

LPM: Conceptualization, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. NAM: Writing – original draft, Writing – review & editing, Conceptualization, Methodology. TFPM: Writing – review & editing. TBMAM: Writing – review & editing. MRFB: Conceptualization, Formal analysis, Methodology, 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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Cognitive performance's critical role in the progression from educational attainment to moderate to vigorous physical activity: insights from a Mendelian randomization study

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Introduction: In individuals with high educational levels, moderate to vigorous physical activity (MVPA) is often elevated, yet the causal direction and the role of cognitive performance in this association remain ambiguous. Herein, Mendel randomization (MR) was employed to measure the causal relationship between education, cognitive performance, and moderate to vigorous physical activity. The purpose of this study was to analyze the causal effects of educational attainment on moderate-to-vigorous physical activity (MVPA) levels and to explore potential mediating factors.

Methods: Two-sample univariate MR analysis was conducted to assess the overall effect of education on moderate to severe physical activity. Besides, a two-step MR analysis was carried out to evaluate the mediating effect of cognitive performance on the impact of education on moderate to severe physical activity. Individuals included were exclusively of European ancestry, with data gathered from extensive genome-wide association studies (GWAS) on education ($n = 470{,}941$), cognitive performance ($n = 257{,}841$), and moderate-to-vigorous physical activity (MVPA) ($n = 377{,}234$). Educational attainment was measured by college graduation status. Cognitive performance encompasses not only psycho-motor speed, memory, and abstract reasoning abilities but also knowledge and skills acquired in professional domains. MVPA is defined as any physical activity that produces a metabolic equivalent (MET) of ≥3.0.

Results: The positive two-sample MR analysis showed that education level had a significant protective effect on MVPA deficiency ($\beta = -0.276$, 95% CI = -0.354 to -0.199, $p = 2.866 \times 10^{-12}$). However, the reverse two-sample MR analysis showed that MVPA had no significant causal relationship with education level ($p = 0.165$). Subsequently, the two-step MR analysis indicated that the potential causal protective effect of education on the risk of MVPA deficiency was mostly mediated by cognitive performance (mediating effect $\beta = -0.235$, 95% CI = -0.434 to -0.036, and the intermediary ratio was 85.061%).

Discussion: Cognitive performance holds considerable significance in the relationship between education level and MVPA. Consequently, the intervention of cognitive performance may greatly improve the risk of physical inactivity caused by education, thereby promoting individual health.

KEYWORDS

cognitive performance, educational attainment, moderate to vigorous physical activity, Mendelian randomization, relationship

1 Introduction

Regular moderate to severe PA (MVPA) can bring more additional health benefits, including reducing the risk of obesity, cardiovascular disease and degenerative symptoms (Mountjoy et al., 2011). As per the World Health Organization's guidelines on physical activity (WHO, 2010), adults should aim for at least 150 min of moderate-intensity physical activity or 75 min of high-intensity physical activity per week, or an equivalent combination of both. However, in 2016, more than a quarter of the world's adults were reported not to get enough physical activity. This left more than 1.4 billion adults vulnerable to developing or worsening diseases associated with physical inactivity, demanding urgent solutions (Guthold et al., 2018).

The level of education is usually measured by educational background or years of schooling. Education level (EA) is moderately heritable (Cutler and Lleras-Muney, 2006; Branigan et al., 2013), and has important correlation with health outcomes (Conti et al., 2010). For example, people with higher education tend to live longer (Mackenbach et al., 2008). Highly educated individuals often possess a better understanding of sports and health, leading them to actively engage in MVPA more frequently. However, there are also studies indicating a positive bivariate correlation between education level and sedentary behavior, and a negative correlation between education level and mild PA (Comes et al., 2019). Therefore, the causal relationship and potential mechanism between education level and physical activity are still unclear, leading to ongoing debates in the field.

Cognitive ability is an important predictor of education, health, and longevity (Lövdén et al., 2020), which usually includes fluid ability and crystallization ability (Baltes et al., 1999). On the one hand, cognitive performance is closely related to education level. In the general population, higher education level is related to higher neurocognitive test performance (Elliott et al., 2019). On the other hand, low cognitive performance often correlates with low levels of physical activity. Patients experiencing cognitive impairment typically engage in minimal physical activity and often struggle with adhering to exercise interventions. Severely mentally ill patients exhibit a notable decrease in strenuous exercise and an increase in sedentary behavior (Stubbs et al., 2016; Vancampfort et al., 2016). Therefore, cognitive performance seems to be a mediating factor in the causal relationship between education level and MVPA.

The recent large-scale genome-wide association study (GWAS) on education (n = 480,941), cognitive performance (n = 257,841) and MVPA (n = 377,234) offers an opportunity to clarify the complex causal relationship through MR analysis. This method uses genetic variation as a proxy for the phenotype of interest (i.e., instrumental variable) to assess causality. In contrast to observational studies, MR analysis benefits from the characteristics of heritable and randomly assigned genetic variation. This advantage allows MR analysis to mitigate potential confounding factors and reverse causal bias (Smith and Ebrahim, 2003; Zheng et al., 2017). The objective of this study is to apply the MR framework to investigate the impact of education and cognitive performance on MVPA levels. For cognitive performance factors that are supported by MR analysis to have a causal effect on MVPA, we aim to further employ MR mediation analysis to examine the extent to which these cognitive factors may mediate the influence of educational attainment. Our research hypotheses are twofold: (1) Educational attainment has a negative linear relationship with the risk of insufficient moderate-to-vigorous physical activity; and (2) Cognitive performance plays a crucial role in the pathway from educational attainment to MVPA. This study has important implications for designing targeted public health policies to improve MVPA and minimize health-related social disparities.

2 Method

Herein, two-sample univariate and two-step MR analyses were employed to assess the causal relationship between education level, cognitive performance, and MVPA (Figure 1). Through univariate MR analysis, the total causal impact of education level on MVPA was evaluated. In addition, two-step MR analysis was carried out to assess the potential mediating role of cognitive performance between education level and MVPA. The GWAS data used in this study were hereby summarized, as shown in Table 1. The genetic association for educational attainment was estimated from a GWAS of 480,941 individuals of European descent (Loh et al., 2018). Educational attainment was harmonized across cohorts using the International Standard Classification of Education (Okbay et al., 2016). Genetic association estimates for cognitive performance were obtained from a GWAS conducted on 257,841 white individuals (Klimentidis et al., 2018). The measure of cognitive performance was the respondent's score on a language-based cognitive test, specifically a cognitive test from the Wisconsin Longitudinal Study (WLS) that has excellent retest reliability and psychometric properties. Genetic association estimates for MVPA were obtained from a GWAS involving 377,234 white individuals (Lee et al., 2018). A large prospective cohort study from the UK Biobank included MVPA-related self-reported outcomes in a manner similar to the International Physical Activity Questionnaire, wrist-worn accelerometer variables, and genetic data. Full details of the GWAS analyses can be found in their original publications.

2.1 Design

MR is a gene-based analysis method that leverages the random distribution of gene variation during pregnancy to infer the causal effect of exposure on the results. SNPs used as genetic tools in MR analysis must meet the following three basic assumptions: (1) Genetic variation must be truly related to exposure; (2) Genetic variation should not be associated with any confounding factors related to exposure outcome; (3) No direct correlation exists between genetic variation and results. Specifically, the inclusion criteria for the (1) relevance assumption: the inclusion criteria were SNPs strongly

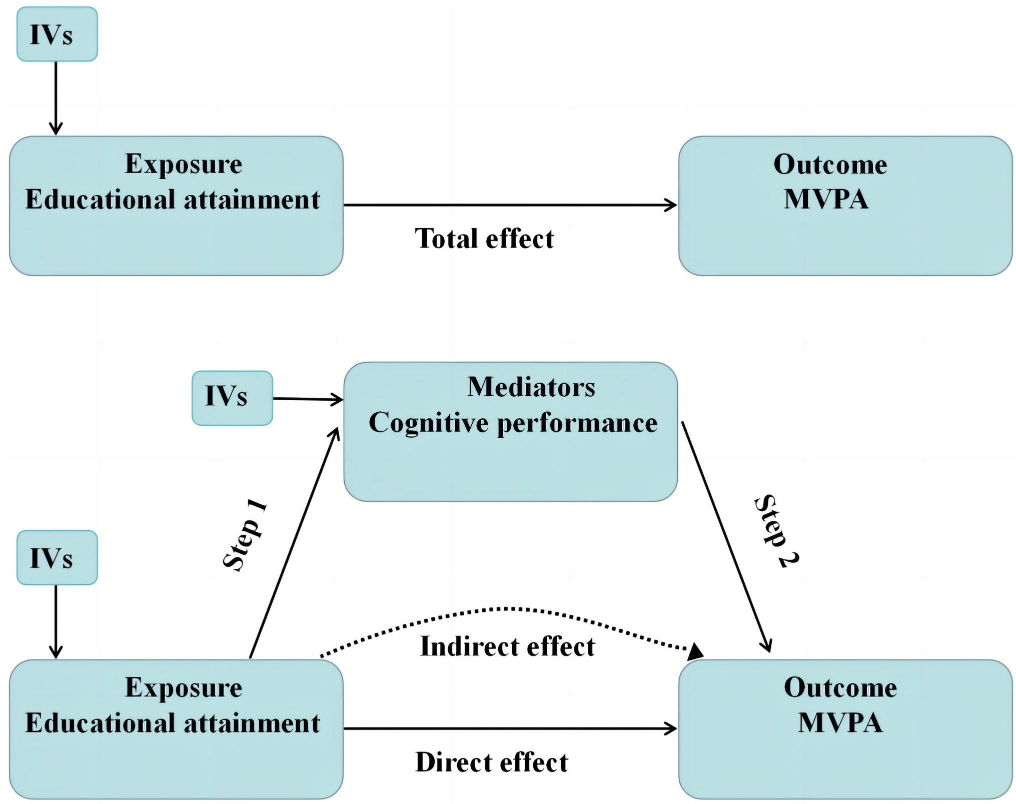

FIGURE 1
Graphical summary of the design of this study.

TABLE 1 Overview of GWAS data used in MR.

Phenotype	Number of participants	Ancestry	Author	Year of publication	Pubmed ID	Source (accessed on 11 April, 2024)
Educational attainment	470,941	European	Loh PR	2018	29,892,013	https://gwas.mrcieu.ac.uk/datasets/ebi-a-GCST90029012/
MVPA	377,234	European	Klimentidis YC	2018	29,899,525	https://gwas.mrcieu.ac.uk/datasets/ebi-a-GCST006097/
Cognitive performance	257,841	European	Lee JJ	2018	30,038,396	https://gwas.mrcieu.ac.uk/datasets/ebi-a-GCST006572/

correlated with the exposure (statistical significance $p < 5 \times 10^{-8}$, linkage disequilibrium $r^2 < 0.001$, strength statistic $F > 10$), while the exclusion criteria were SNPs not significantly or weakly correlated with the exposure factors; (2) independence assumption: the inclusion criteria were SNPs unrelated to confounders, and the exclusion criteria were SNPs associated with multiple confounders or known genetic factors influencing the outcome; (3) exclusion-restriction assumption: the inclusion criteria were SNPs unrelated to the outcome, and the exclusion criteria were SNPs related to the outcome. More details of this method have been previously described (Dimou and Tsilidis, 2018). The present study adhered to the STROBE-MR guidelines (Skrivankova et al., 2021). In addition, the present analysis lacked preview registration, so the results should be considered exploratory.

2.2 Data sources

Therefore, each exposure instrument considered in the univariable MR analyses was selected as variants associated with genome-wide significance ($p < 5 \times 10^{-8}$), linkage disequilibrium $r^2 < 0.001$, and clustered variants distance >10,000 kb with the exposure. Additionally, to assess instrument strength, F statistics were calculated for each genetic instrument. In cases where the target SNP was unavailable in the result dataset, a proxy SNP with an $R2 > 0.8$ was used as a substitute. A total of 205 education level SNPs (Supplementary Table S1) were selected as genetic tools. Herein, the average F statistic of education level was 45.885 (ranging from 28.913 to 198.930) (Supplementary Table S2). Besides, a total of 19 MVPA SNPs (Supplementary Table S3) were selected as genetic tools. The average F statistic of MVPA was 34.393 (ranging from 29.984 to 51.824) (Supplementary Table S4). Additionally, 139 cognitive performance SNPs (Supplementary Table S5) were selected as genetic tools. The average F statistic of cognitive performance was 43.742 (ranging from 29.793 to 125.282) (Supplementary Table S6).

2.3 Preliminary analysis

In this study, a single-variable MR approach was employed. Specifically, a two-sample two-way MR analysis was conducted to evaluate the causal relationship between education level and MVPA. The instrumental variable for the exposure data, derived from the GWAS results, was extracted using the SNP tool. In order to ensure correct coordination of alleles, SNPs were targeted, so that the effect variants of exposure and results corresponded to the same allele (Hemani et al., 2018). The main result was generated using the inverse variance weighted (IVW) method of random effects. It should be noted that the IVW method provides unbiased estimates only when the assumption of balanced or non-existent pleiotropy holds (Hemani et al., 2018). Other MR methods included MR Egger, Weighted media, Weighted mode, and Simple mode.

For all significant MR results regarding the association between education level and physical activity, a two-step MR analysis was conducted to examine the potential mediating effect of cognitive performance. Two-step MR assesses whether intermediate traits act as mediators between exposure and outcome (Relton and Davey Smith, 2012). When exposure affected mediating variables and then impacted outcomes, the "coefficient product" was utilized (VanderWeele, 2016). Subsequently, the total effect of education level was decomposed into direct effects (i.e., the impact of education level on MVPA irrelevant to mediation) and indirect effect (i.e., the influence of education level on MVPA through mediation). Currently, this method has been extensively used (Burgess et al., 2015).

2.4 Sensitivity analysis

A genetic variation was deemed weak when the F-statistic was below 10. Such weakness might introduce deviations in the results (Palmer et al., 2011). In addition, multiple sensitivity analysis was conducted to verify the robustness of MR inspection, such as MR Egger intercept test, Cochran's Q test, MR pleiotropic residual sum and leave-one-out analysis. Furthermore, all MR analyses were conducted using the TwoSampleMR package (version 0.5.8) in R (version 4.3.2). The original data and code files were stored in the Open Science Framework.[1]

1 https://osf.io/crwah/

2.5 Measuring the strength of evidence

Beta is the causal effect size we aim to estimate, i.e., the impact of the exposure factor on the outcome variable. CI is the confidence interval of the estimated parameter; usually, a 95% confidence interval is given to indicate the uncertainty of the estimated effect (Bland and Altman, 1996). The *p*-value is the *p*-value for testing the statistical hypothesis, used to evaluate whether the observed effect is statistically significant. In this study, the beta and its 95% CI and *p*-value data were all calculated and generated by the statistical software R. In this study, we not only use *p*-value thresholds to indicate statistical significance but also interpret the evidence provided by the results by examining the magnitude of the effect of interest and the width of its 95% confidence interval, combined with the consistency of the results from the different methods employed (Wasserstein et al., 2019).

3 Results

3.1 Causal effect of educational attainment on physical activity levels

Univariate positive MR analysis was hereby conducted to determine the protective effect of education level on MVPA deficiency. Higher education was found to be negatively correlated with lower MVPA (IVW: $\beta = -0.276$, 95%CI $= -0.354$ to -0.199, $p = 2.866 \times 10^{-12}$). Consistent univariate results were observed when using Weighted media, Simple mode, and Weighted mode analysis (Supplementary Figure S1; Supplementary Table S7). In all analyses, the MR Egger intercept was close to zero, and the 95% CI was narrow. There was indication of SNP effect heterogeneity, but none of the analyses pinpointed specific SNPs as drivers of the causal relationship (Supplementary Figure S2).

The reverse MR analysis showed that MVPA did not affect educational attainment (IVW: $p = 0.165$). Consistent negative results were obtained using other MR methods ($p > 0.05$) (Supplementary Table S8). The MR Egger intercept of all analyses was close to zero, indicating that horizontal pleiotropy did not significantly impact the MR results. Besides, Cochran's Q test showed the heterogeneity of SNP effect. However, one analysis left did not uncover any abnormal values (Supplementary Figure S3), and the funnel chart was roughly symmetrical on both sides (Supplementary Figure S4). The huge difference between univariate forward MR analysis and reverse MR analysis results (Figure 2) indicated that the causal effect of education on MVPA might depend on mediators.

3.2 Intermediary analysis

Through a two-step MR analysis, the causal link between education level and MVPA mediated by cognitive performance indicators was examined. Initially, education level was utilized as an instrumental variable to assess the causal relationship between the exposure and potential mediators. In terms of education level and mediation, a significant causal relationship was observed (Supplementary Table S9) (IVW: $\beta = 1.639$, 95%CI $= 1.517$ to 1.760, $p = 3.198 \times 10^{-154}$). Secondly, a relationship between cognitive performance and MVPA deficiency was identified by using genetic instruments of cognitive performance to

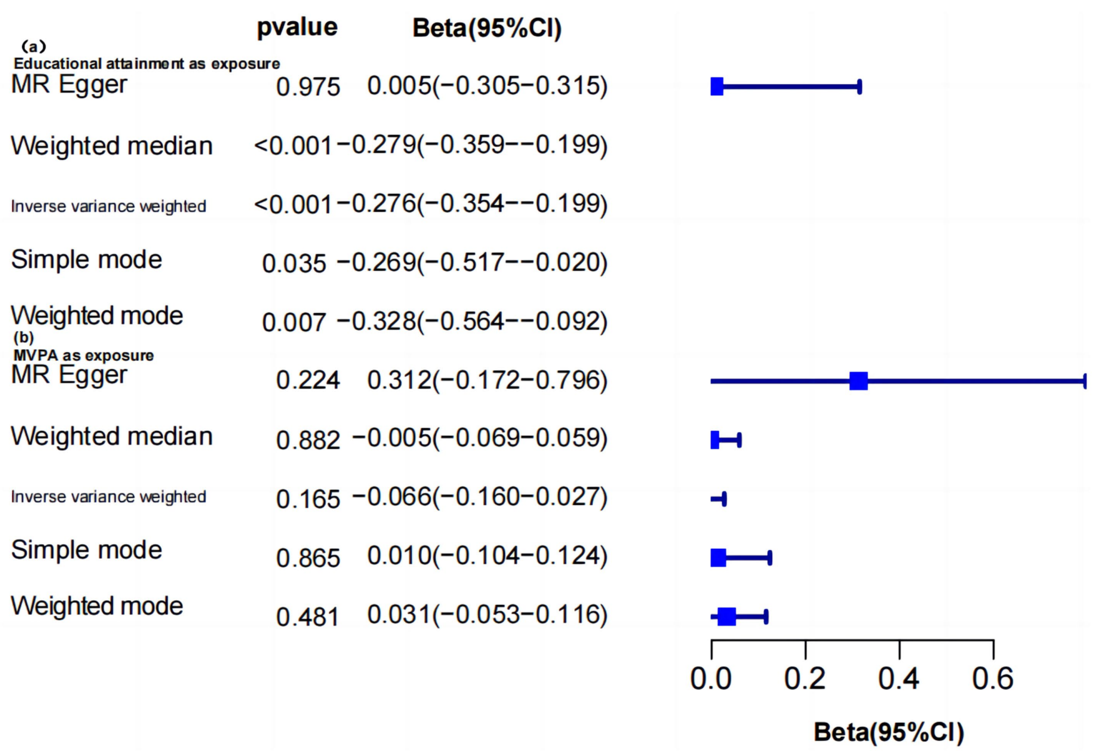

FIGURE 2
Two-way MR results between education level and MVPA.

TABLE 2 Mediating effect of education level on MVPA's cognitive performance.

Mediator	Total effect β (95% CI)	Direct effect A (95% CI)	Direct effect B (95% CI)	Mediation effect (95% CI)	Types of mediation	Mediator
Cognitive performance	−0.276 (−0.354 to −0.199)	1.639 (1.517 to 1.760)	−0.143 (−0.175 to −0.111)	−0.235 (−0.434 to −0.036)	Partial mediation	85.06%

"Direct effect A" indicates the influence of education level on cognitive performance; and "Direct effect B" indicates the influence of cognitive performance on MVPA.

assess the causal impact of mediators on MVPA deficiency (Supplementary Table S10) (IVW: β = −0.143, 95%CI = −0.175 to −0.111, $p = 1.2 \times 10^{-18}$). Mediation analysis showed that the impact of education level on MVPA was mostly mediated by cognitive performance, and the mediating effect of cognitive performance (β = −0.235, 95% CI = −0.434 to −0.036). Besides, the intermediary ratio was 85.061% (Table 2).

4 Discussion

In this study, the causal impact of education on MVPA was explored using genetic variation as a non-confounding proxy univariate MR analysis. Through the application of five complementary univariate MR methods with distinct basic assumptions, the findings consistently indicated a positive correlation between higher education levels and a reduced risk of MVPA. Moreover, the reverse MR analysis demonstrated that MVPA had no causal effect on education level. Furthermore, given the significant contrast in the causal effects estimated by univariate forward MR analysis and reverse MR analysis, a two-step MR analysis was further conducted. This approach revealed that the influence of education level on the risk of MVPA deficiency primarily stemmed from the protective effect of cognitive performance, with education level playing a partial role. Our work leverages large-scale GWAS data to investigate the effects of genetically predicted educational attainment and cognitive performance on MVPA risk within the MR framework, providing evidence supporting the protective roles of education and cognitive performance. Following extensive sensitivity analyses and multiple validity assessments, the results remained robust.

Our MR analyses identified a protective effect of genetically predicted educational attainment on MVPA risk. Our findings align with previously published research conclusions. Specifically, elementary schools often adopt recess, classroom PA breaks, before- and after-school programs, and integration of PA with academic lessons to create healthy school environments that promote students reaching recommended MVPA levels (Committee on Physical Activity and Physical Education in the School Environment et al., 2013). Higher education institutions typically provide more supportive environments for promoting students meeting MVPA guidelines, such as highly professional physical education faculty, rich and diverse sports club activities, and sufficient advanced sports facilities (Carlson et al., 2014). Educational attainment may also influence individuals' socioeconomic resources and environmental exposures in adulthood, directly or indirectly determining access to quality healthcare, including exercise prescription interventions to achieve MVPA recommendations (Ceci, 1991). Further research indicates that parental education level in the family can impact children's MVPA frequency (Jiménez-Pavón et al., 2012). Parents support their children's MVPA levels by indirectly encouraging or directly taking them to engage in physical exercise (Gustafson and Rhodes, 2006).

On the other hand, our current work also improves upon some previous studies. Specifically, increasing evidence from behavioral research and neuroscience suggests that motor and cognitive development are inherently intertwined (Zhou and Tolmie, 2024). Physical activity has been found to be significantly associated with cognitive performance in children and adolescents (Zhang et al., 2022). Furthermore, our MR study explores the negative correlation between cognitive performance and MVPA risk, as we employ more genetic instruments for cognitive performance and provide greater robustness against potential violations of MR modeling assumptions. The protective effect of cognitive performance on MVPA risk may be attributed to good cognitive performance assisting individuals in adopting and adhering to healthy behaviors, as well as increasing awareness of the detrimental effects of sedentary behavior and knowledge about the health benefits of MVPA (Bor et al., 2017).

The association between education and cognitive ability is evident across the adult lifespan and the entire educational spectrum. Evidence suggests that cognitive ability is related to the choice to pursue longer education, particularly higher education, with higher educational attainment correlating with higher baseline cognitive levels (Lövdén et al., 2020). Concurrently, compared to individuals with lower educational attainment, those with higher education have a reduced risk of dementia and Alzheimer's disease (AD) in old age (Karp et al., 2004; Caamaño-Isorna et al., 2006). Consistent with these results, our MR study reports a positive impact of education on cognitive function. A possible explanation is that education may influence cognitive ability development through a broad foundation of specific knowledge and skills, such as improvements in memory, reasoning, cognitive strategies, and test-taking abilities. It is well known that educational attainment is heritable, and cognitive performance is considered a downstream regulatory factor of education. Thus, our evidence supports that the protective effect of education on MVPA risk is primarily mediated through cognitive performance, with the underlying mechanism potentially related to the exceptional self-management awareness and exercise health participation practices provided to highly educated individuals.

Therefore, it was hereby proposed that schools held an indisputable responsibility for fostering the healthy development of students. This involved instilling a cognitive understanding of health and promoting a correct comprehension of MVPA. Additionally, implementing MVPA interventions was essential to assist students in achieving the recommended levels and reaping the benefits of MVPA. The correct cognition in student days and the habit of regular MVPA exercise could facilitate individuals to maintain a healthy lifestyle in future life. As students transition into society, it is vital for society to offer necessary support, including fostering a positive social sports atmosphere, providing ample sports opportunities, and ensuring top-notch sports infrastructure. Ultimately, individuals must translate their understanding of the importance of MVPA into daily behavior and maintain consistent practice in their everyday lives.

5 Advantages and limitations

This study made the first attempt to comprehensively investigate the causal relationship between education level, cognitive performance, and MVPA using the MR method, serving as a genetic tool selected from the GWAS of the largest and latest education level, cognitive performance, and MVPA. Under the univariate MR design, a series of sensitivity analyses were conducted to control the bias of multiple validity and verify the robustness of MR results. This research, employing genetic tools, unveiled the predominant causal link between cognitive performance and the relationship between education level and MVPA. Overall, the discovery offers fresh insights into the social disparities in MVPA behavior and health inequality.

However, the research results still have some limitations to be considered when interpreting the results. First, there was evidence of heterogeneity implied by Cochran Q statistics. To solve this problem, the IVW random effects method was chosen as the main MR method, which was robust to heterogeneity. Secondly, in the MR analysis of two samples, sample overlap might introduce potential deviation. Since most of the genetic variations used in the analysis were strong IV, F statistic > 28.913, and were related to $p < 5 \times 10^{-8}$ exposure, any deviations from the expected outcomes were expected to be minimal. Finally, to address population stratification, the present analysis focused solely on individuals of European descent. However, further research involving other racial groups is still warranted to ensure broader applicability of the findings.

Therefore, it was hereby proposed that schools held an indisputable responsibility for fostering the healthy development of students. This involved instilling a cognitive understanding of health and promoting a correct comprehension of MVPA. Additionally, implementing MVPA interventions was essential to assist students in achieving the recommended levels and reaping the benefits of MVPA. The correct cognition in student days and the habit of regular MVPA exercise could facilitate individuals to maintain a healthy lifestyle in future life. As students transition into society, it is vital for society to offer necessary support, including fostering a positive social sports atmosphere, providing ample sports opportunities, and ensuring top-notch sports infrastructure. Ultimately, individuals must translate their understanding of the importance of MVPA into daily behavior and maintain consistent practice in their everyday lives. Our research findings support the potential causal protective effect of educational attainment on MVPA risk, which is mediated by cognitive performance. Therefore, educational level and cognitive functioning may serve as public health targets for reducing the risk of MVPA.

6 Conclusion

This study utilizes genetic data from MR analysis to generate evidence supporting the protective role of education, with evidence indicating that the impact of education is primarily mediated through cognitive performance. One plausible explanation for the crucial role of cognitive functioning is its potential to exert widespread beneficial effects on health. These findings underscore the importance of educational attainment and cognitive performance as partial determinants of MVPA risk, which may serve as potential targets for reducing health inequalities stemming from MVPA risk.

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 GWAS data utilized in this study were sourced from the UK Biobank, a publicly accessible resource available for download by qualified researchers. Prior to participation, all subjects provided written, informed consent. Ethical approval for the UK Biobank study was granted by the North West Multi-Centre Research Ethics Committee, the National Information Governance Board for Health and Social Care (NIGB), and the Community Health Index Advisory Group (CHIAG), authorizing research involving human participants.

Author contributions

FQ: Writing – review & editing. ZJ: Writing – original draft.

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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.2024.1421171/full#supplementary-material

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Analyzing activity and injury risk in elite curling athletes: seven workload monitoring metrics from session-RPE

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Objective: The study aimed to compare the differences in the performance of seven session-rating of perceived exertion (RPE)-derived metrics (coupled and uncoupled acute: chronic workload ratio (ACWR), weekly ratio of workload change, monotony, standard deviation of weekly workload change, exponentially weighted moving average (EWMA), and robust exponential decreasing index (REDI)) in classifying the performance of an injury prediction model after taking into account the time series (no latency, 5-day latency, and 10-day latency).

Design: The study documented the RPE of eight curlers in their daily training routine for 211 days prior to the Olympic Games.

Methods: Seven Session-RPE (sRPE)-derived metrics were used to build models at three time series nodes using logistic regression and multilayer perceptron. Receiver operating characteristic plots were plotted to evaluate the model's performance.

Results: Among the seven sRPE-derived metrics multilayer perceptron models, the model without time delay (same-day load corresponding to same-day injury) exhibited the highest average classification performance (86.5%, AUC = 0.773). EMWA and REDI demonstrated the best classification performance (84.4%, $p < 0.001$). Notably, EMWA achieved the highest classifying accuracy in the no-delay time series (90.0%, AUC = 0.899), followed by the weekly load change rate under the 5-day delay time series (88.9%, AUC = 0.841).

Conclusion: EWMA without delay is a more sensitive indicator for detecting injury risk.

KEYWORDS
session-RPE, injury classification, neural network, workload, injury risk

1 Introduction

RPE was first pioneered by Borg in the 1960s and 1970s to engage in research related to the perception of physical exertion, and he also proposed the 6–20 scale, the CR-10 scale, and the CR-100 scale (1). The study by Banister et al. proposed a stimulus-fatigue model on exercise load and the concept of training impulse (TRIMP) and quantified and monitored internal load characteristics in various competitive sports based on HR (2). Researcher Foster, influenced by the studies of the previous two scholars, optimized the CR-10 scale and proposed Foster's modified version of the CR-10 RPE scale, which is currently the most widely used in competitive sports (3). In the subsequent studies, he proposed the sRPE load monitoring method, which quantifies the training/competition load by monitoring the duration of the training/competition combined with the RPE after training/competition, in which session refers to the duration of training/competition, i.e., Work Load of training/competition = RPE × Session Duration(min), A.U. (Arbitrary Units) (4). sRPE is a method to monitor the average intensity of training/competition, which is of great practical value and provides conditions for the effective quantification of exercise load (5).

ACWR is the most commonly used indicator for assessing injury risk in the practice of sRPE, with ACWR between 0.8 and 1.3, athletes are at low risk of injury, and with ACWR above 1.5, the risk of injury is significantly increased (6), and Gabbett suggests that with ACWR between 0.8 and 1.3, athletes are at low risk of injury and are in a "green zone" (7), and with ACWR above 2, the non-contact injury rate increases by 5–6 times (7). Gabbett suggested that athletes with an ACWR of 0.8–1.3 have a low risk of injury and are in a "green health zone" (7). He also noted that the rate of non-contact injuries increases by a factor of 5–6 when the ACWR exceeds 2 (8) and that ACWR is significantly correlated with the risk of non-contact injuries, but that program variations make it impossible to determine the ACWR threshold for the smallest risk of injury (9).

The value of the coupled ACWR for use during training is worth determining, but its reliability has been questioned. The coupled ACWR is a ratio of activity loads and is not a measure of change, while simply going through the ratio to normalize acute loads into chronic loads is mathematically inaccurate and is required to be predicated based on the existence of a linear relationship between the numerator and denominator in the ratio (10). The essence of this is that acute load is higher than past chronic load and injury risk increases, and excessively lower than chronic load and injury risk increases. However, there are limitations in that the coupled ACWR creates a spurious correlation between acute and chronic loads, resulting in a reduction in interval workload variability. Many athletes will adjust their athletic status and recover from high-intensity training by decreasing the amount of training prior to the competition. The performance of ACWR will differ significantly from the actual situation; there are a large number of confounding factors, similar to the pre-competition reduction in the actual process, which results in a forced decrease in load, causing a rapid change in the tendency of the ACWR, but there is no risk of injury (11). Otherwise, there is sometimes a lag in the occurrence of injury, i.e., an injury from an overloaded training session in the current week may occur in the following week, and this injury is calculated into the load of the following week in the algorithm of the coupled ACWR, resulting in a decrease in sensitivity (12). In addition, the average loading calculation ignores intensity stimuli during the loading effect and reduces the effect of training intensity peaks on the loading effect over time. Conversely, the weighted loading approach, which increases the weight of recent training through the weighting factor, has the disadvantage of being particularly sensitive to missing data halfway through the process (13).

Therefore, different researchers have proposed different coping strategies based on their studies to address the above-mentioned problems. Researcher Lolli supports the effectiveness of uncoupled ACWR in improving variability, i.e., not including acute loads in rolling loads to increase their variability (14). Researcher Williams refined the problem of load time series accumulation by proposing an algorithm for load weighting of sRPE decaying over time, EWMA (11). Researcher Montini, based on Williams' study, added a lag perspective to correspond the previous week's damage to the current week's load, and the findings affirmed the correlation between lagged damage and load (12). Researcher Moussa introduced a natural logarithmic weight, the REDI, to optimize the negative impact of missing data on the overall data analysis (13). Researchers Lazarus and Tysoe, on the other hand, used a new tool, the rate of change of weekly load and the standard deviation of weekly load change, to study the relationship between load and injury risk, and the results concluded that when the load increases by 1 standard deviation, it will cause the risk of injury, and when it increases by 2 standard deviations, it will cause a high risk of injury (15, 16). Meanwhile, for the traditional means of risk correlation analysis, the use of artificial neural networks in machine learning to analyze will achieve better results (17). However, there are still many controversies about the effectiveness of the optimization means of ACWR, and coupled and uncoupled ACWR do not seem to have much difference in estimating injury risk (18). The findings of some other researchers affirm that EWMA is more sensitive than ACWR in injury risk association. There are also studies that show REDI captures injury risk better than ACWR and EWMA (19), but REDI's findings are based on simulated data, and its real-world application is still questioned.

Curling is a sport dominated by technical and tactical skills. On the international stage, the injury rate and severity in curling are relatively low, and the athletic lifespan of curlers is long, making injury management crucial (20). As curlers age in their sport, their experience grows richer, which is critical for a non-contact sport. Injuries in curling are predominantly chronic, often stemming from fatigue accumulation and prolonged abnormal movement patterns (21). The sport's workload encompasses both psychological and physiological dimensions, making the sources of this load complex and ambiguous, which complicates injury prevention for coaches and team doctors. The integration of computer science into sports science is a direction for the development of competitive sports. Numerous studies currently use machine learning to identify risk factors for injuries. sRPE is a straightforward method for monitoring workload, and if combined with machine learning to optimize its shortcomings, it could better help control injury risks. In Palmer's research (22), machine learning and sRPE were used to identify sensitive factors for injury risk, but the study did not explore various derivative algorithms of ACWR. Maintaining long-term physical health is vital for curlers. Given their extended athletic lifespan, curling requires a simpler, more convenient, and cost-effective method for workload monitoring, which sRPE can effectively provide.

This study aimed to explore the sensitivity of coupled ACWR, uncoupled ACWR, weekly load change rate, monotony, standard deviation of weekly load change, EWMA, and REDI to capture injury risk at different lags after logistic regression and neural network modeling, and to search for the best ACWR optimization under one optimal lag period means to correlate injury risk, to help the trainer's training program development and revision process.

2 Methods

2.1 Participants

The subjects were eight members of the Chinese National Men's Curling Training Team preparing for the Winter Olympic Games, with

TABLE 1 Basic information table of participants in the experiment.

	Position first and second (n = 4)	Position third and fourth (n = 4)	All (n = 8)
Age (year), mean (range)	25.5 (22–25)	28 (25–31)	26.8 (22–31)
height (cm), mean (SD)	182.8 (5.9)	179.5 (3.7)	181.1 (4.9)
weight (kg), mean (SD)	81.3 (1.7)	73.1 (4.8)	77.2 (5.5)
BMI (kg/m^2), mean (SD)	24.4 (1.2)	22.6 (0.7)	23.5 (1.3)
Skeletal muscle (kg), mean (SD)	40.7 (1.5)	36.4 (2.6)	38.6 (3.0)
Body fat (%), mean (SD)	12.5 (2.1)	12.7 (1.3)	12.6 (1.6)
Training year (year), mean (SD)	7.8 (1.5)	9.5 (1.9)	8.6 (2.4)

an average age of 26.8 years (22–31 years), an average height of 181.1 ± 10.7 years, an average body weight of 77.2 ± 5.5 years, and an average number of years of training of 8.6 ± 2.4 years. All athletes provided an informed consent form. The collection period was 211 consecutive days (Table 1).

2.2 RPE collection

The training duration and RPE of the athletes for field training and physical training were collected 15–30 min after the end of training using the Borg CR-10 scale (5). Athletes who had an injury stoppage were scored as 0 A.U. on that day if there was no other form of practice. Training duration was defined in this study as the period from the start of training to the end of training. The "start of training" was defined in this study as the "start of training" when the athletes entered the field to start the official training program developed by the coaches after the uniform standardized warm-up. The "end of training" is defined as the athlete completing the formal training tasks formulated by the coaches and leaving the main training site, which is the end of training, excluding the process of relaxation and stretching after training. Combined with the actual situation of training, the training week is 5 days, the first 4 days for a number of field training and physical training, and the fifth day for rest.

2.3 Index calculation

RPE was used in this study using Foster's modified version of the CR-10 RPE scale (3), and workload (4) was calculated as follows:

$$\text{Workload} = \text{RPE} \times \text{training duration}\,(\text{min}), \text{A.U.}(\text{Arbitrary Units})$$

In ACWR, acute load was recorded as the sum of the daily workload during the last 1 week, and chronic load was recorded as the weekly average of the sum of workload during the last 4 weeks (7). The ACWR was calculated as follows:

$$Coupled\ \ ACWR = \frac{Workload_{1\ week}}{Workload_{Average\ 4\ weeks}}$$

In the uncoupled ACWR, acute load was recorded as the sum of the daily workload during the last 1 week, and chronic load was recorded as the weekly average of the sum of the workload during the last 3 weeks (14). The ACWR was calculated as follows:

$$Uncoupled\ \ ACWR = \frac{Workload_{1\ week}}{Workload_{Average\ 3\ weeks}}$$

The weekly ratio of workload change is the ratio of the sum of the workload of the last week to the sum of the workload of the previous 1 week (16). The Diff was calculated as follows:

$$Diff = \frac{Workload_{last\ week}}{Workload_{previous\ week}}$$

Monotony is the ratio of the most recent 1-week workload to the standard deviation of the weekly workload (23). The monotony was calculated as follows:

$$Monotony = \frac{Workload_{last\ week}}{WeeklyWorkload_{SD}}$$

The standard deviation of weekly workload change is the difference between the most recent 1-week workload and the average weekly workload, vs. the variance of the weekly workload (15). The SDΔ was calculated as follows:

$$\text{SD}\Delta = \frac{Workload_{last\ week} - Week\ \ Workload_{average}}{Week\ \ Workload_{variance}}$$

EWMA is based on Williams' study (11) and the actual training period design in this study, with a decay time of $N = 5$. The EWMA ACWR was calculated as follows:

$$EWMA_{today} = Workload_{today} + \left(\left(1-\lambda\right) \times EWMA_{\text{yesterday}}\right)$$

$$\lambda = \frac{2}{N+1},\ \lambda \in \left(0,\ 1\right)$$

$$ACWR_{EWMA} = \frac{EWMA_{1\ week}}{EMWA_{\text{average}\ 4\ week}}$$

REDI based on Moussa's study (13), in this study, taking into account the problem of actual rest days for training and maintaining consistency with the EWMA time-decrement weighting form, the natural logarithmic time-decrement in this study was performed only during the week, without weighting the full training day, and for the rest days occurring due to objectively uncontrollable factors in the training process, the same time-decrement clearing is performed, and time-decrement weighting is reapplied on the following day operations. The REDI ACWR was calculated as follows:

$$REDI_{\text{today}} = \frac{1}{\sum_{i=1}^{N} \alpha_i} \times \sum_{i=0}^{N} \alpha_i \times Workload_{today}$$

$$\alpha_i = e^{-i}; \text{if workload is missing, } \alpha_i = 0$$

$$ACWR_{REDI} = \frac{REDI_{1\text{week}}}{REDI_{\text{average}4week}}$$

2.4 Definition of injury

The present study was based on the International Olympic Committee Joint Statement (24), which statistically defines injury and illness as one complete injury or illness from the time it occurs to the time of full recovery after receiving medical treatment. Injury definition, classification (site, severity, type, etc.), and mechanism were referred to high-confidence statistical studies of sports injuries or the latest official consensus statement (24), and the decision was ultimately made by two physicians with more than 3 years of clinical experience and qualified as clinicians. It is important to note that the same injury or disease that persists without full recovery is still recognized as one injury; the same injury or disease that recurs after full recovery is recognized as two injuries. The injury assessments in this study were conducted by experienced physicians serving the national team, who evaluated the prevalence and causes of injuries without using any scales or questionnaires.

2.5 Statistical analysis

The experimental data were subjected to data computation through Octave 4.0.0, and secondary processed data were analyzed through SPSS 26.0 and plotted through GraphPad Prism 9.5.1. The data of the study were measured and expressed as mean ± standard deviation (mean ± SD). The injury-to-non-injury sample ratio in this study was 38:174. Impairments during the analysis were in the form of least squares classification (impairments were recorded as 1 and non-impairments as 0). The problem of the difference in magnitude between different data was taken into account during the analysis, thus all data except injury data were standardized before logistic regression and neural network modeling. In the neural network modeling process, the hidden layer activation function is a hyperbolic tangent function; the output layer activation function is SoftMax; and the error function is cross-entropy. The training set was uniformly randomly selected as 70% of the data set to train the model, and the remaining 30% of the data set was used as the test set to test the model performance and generalization ability, and the data in the test set were not involved in the process of training the model. The neural network model's architecture and termination criteria were automated, with a minimum of 1 and a maximum of 50 units in the hidden layers. The model used the scaled conjugate gradient algorithm, with an initial Lambda value of 0.0000005 and an initial Sigma value of 0.00005. The area under the ROC curve (AUC) was used to evaluate the model's performance (16). The confidence intervals for the models involved in the study are all 95%.

3 Results

3.1 Logistic regression

When comparing the results of 7 means logistic regression under different lag periods, the logistic regression results under no-lag period are better in terms of correct rate and significance, but this is due to the increase of non-injury samples caused by the algorithm under the lag period, and the source of the correct rate is the non-injury classification of the non-injury samples, implying that all non-injury sample predictions are correct. For the damaged samples, the correct classification rate is extremely low, with only 5 cases (out of 38) correctly classified under no lag, 1 in coupled ACWR and 2 each in EWMA and REDI; 1 case correctly classified under 5-day lag, in monotony; and 1 case correctly classified under 10-day lag, in uncoupled ACWR. The reason for this is considered more as a result of chance than model performance. Therefore, logistic regression does not perform well in the actual classification of injury and non-injury samples. This is due to the fact that there is a bias between injury and non-injury samples in the actual process, and the actual training process will reduce the appearance of injury samples through a variety of external interventions, and the logistic regression is not sensitive to the data characteristics of capturing a limited number of samples (Tables 2–4).

3.2 Multilayer perceptron

Comparing the results of the seven means of artificial neural networks under different lags, the seven sRPE-derived metrics multilayer perceptron models showed good classification performance in all three time series nodes (average classification accuracy: no delay >5-day delay >10-day delay, 86.5% > 79.1% > 76.6%); average AUC: no delay >5-day delay >10-day delay (0.773 > 0.645 > 0.627). In the no-lag period, the highest correct classification rate was for the coupled ACWR, but its AUC was not high, and model screening revealed that the reason originating from the excessively high number of non-injury samples in the randomized test set caused it to appear high despite its low AUC, whereas the EWMA maintained a high rate of correct classification (90%) despite its high AUC (AUC = 0.899). In the 5-day lag period, the weekly load change rate performed best, maintaining a high rate of correct classification (88.9%) despite a high AUC (AUC = 0.841). In the 10-day lag period, the overall classification model performed poorly, with monotony, a standard deviation of weekly load change, and EWMA having an AUC close to 0.5, and its classification performance was not satisfactory (Tables 5–7).

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TABLE 2 Logistic regression results without delay.

	B	SD	Wald	*p*	Exp(B)	EXP(B) 95%CI		Accuracy
						Lower	Upper	
ACWR[a]	4.565	1.091	17.517	0.000	96.093	11.329	815.042	82.5%
UnACWR[b]	−2.432	0.859	8.024	0.005	0.088	0.016	0.473	82.1%
Diff[c]	0.811	0.459	3.130	0.077	2.251	0.916	5.528	82.1%
Monotony[d]	−0.035	0.028	1.561	0.212	0.966	0.914	1.020	82.1%
SD[e]	0.809	0.210	14.851	0.000	2.246	1.488	3.389	82.1%
EWMA[f]	5.653	1.252	20.403	0.000	285.198	24.538	3314.824	84.4%
REDI[g]	4.664	1.182	15.580	0.000	106.102	10.468	1075.432	84.4%

[a]Coupled acute:chronic workload ratio.
[b]Uncoupled acute:chronic workload ratio.
[c]Weekly ratio of workload change (%).
[d]Monotony.
[e]Standard deviation of weekly workload change.
[f]Exponentially weighted moving average.
[g]Robust exponential decreasing index.

TABLE 3 Logistic regression results with a 5-day delay.

	B	SD	Wald	*p*	Exp(B)	EXP(B) 95%CI		Accuracy
						Lower	Upper	
ACWR[a]	1.789	0.902	3.934	0.047	5.983	1.021	35.045	81.9%
UnACWR[b]	−1.049	0.665	2.488	0.115	0.350	0.095	1.290	81.9%
Diff[c]	1.522	0.489	9.681	0.002	4.581	1.756	11.949	81.9%
Monotony[d]	0.025	0.013	3.852	0.050	1.025	1.000	1.052	82.8%
SD[e]	0.364	0.180	4.064	0.044	1.438	1.010	2.048	81.9%
EWMA[f]	0.998	0.918	1.183	0.277	2.714	0.449	16.396	81.9%
REDI[g]	1.565	0.914	2.932	0.087	4.782	0.798	28.668	81.9%

[a]Coupled acute:chronic workload ratio.
[b]Uncoupled acute:chronic workload ratio.
[c]Weekly ratio of workload change (%).
[d]Monotony.
[e]Standard deviation of weekly workload change.
[f]Exponentially weighted moving average.
[g]Robust exponential decreasing index.

TABLE 4 Logistic regression results with a 10-day delay.

	B	SD	Wald	*p*	Exp(B)	EXP(B) 95%CI		Accuracy
						Lower	Upper	
ACWR[a]	−1.553	0.841	3.407	0.065	0.212	0.041	1.101	80.7%
UnACWR[b]	0.826	0.408	4.104	0.043	2.283	1.027	5.075	81.7%
Diff[c]	−0.230	0.497	0.214	0.644	0.795	0.300	2.103	80.7%
Monotony[d]	−0.300	0.025	1.394	0.238	0.971	0.924	1.020	80.7%
SD[e]	−0.283	0.169	2.790	0.095	0.753	0.541	1.050	80.7%
EWMA[f]	−1.302	0.864	2.269	0.132	0.272	0.050	1.480	80.7%
REDI[g]	−1.112	0.816	1.860	0.173	0.329	0.066	1.626	80.7%

[a]Coupled acute:chronic workload ratio.
[b]Uncoupled acute:chronic workload ratio.
[c]Weekly ratio of workload change (%).
[d]Monotony.
[e]Standard deviation of weekly workload change.
[f]Exponentially weighted moving average.
[g]Robust exponential decreasing index.

TABLE 5 Multilayer perceptron results without delay.

	Cross-entropy error		AUC		Accuracy
	Training set	Test set	Injury	Non-injury	
ACWR[a]	72.495	14.620	0.714	0.714	91.3%
UnACWR[b]	60.989	13.893	0.815	0.815	87.2%
Diff[c]	49.812	16.491	0.862	0.862	79.1%
Monotony[d]	62.575	27.331	0.715	0.715	82.5%
SD[e]	69.578	19.527	0.687	0.687	88.1%
EWMA[f]	42.075	13.104	0.899	0.899	90.0%
REDI[g]	73.951	18.405	0.721	0.721	87.2%

[a]Coupled acute:chronic workload ratio.
[b]Uncoupled acute:chronic workload ratio.
[c]Weekly ratio of workload change (%).
[d]Monotony.
[e]Standard deviation of weekly workload change.
[f]Exponentially weighted moving average.
[g]Robust exponential decreasing index.

TABLE 6 Multilayer perceptron results with a 5-day delay.

	Cross-entropy error		AUC		Accuracy
	Training set	Test set	Injury	Non-injury	
ACWR[a]	63.194	20.846	0.700	0.700	78.0%
UnACWR[b]	67.987	21.147	0.613	0.613	76.9%
Diff[c]	55.881	11.559	0.841	0.841	88.9%
Monotony[d]	58.756	33.116	0.619	0.619	78.1%
SD[e]	63.234	31.830	0.592	0.592	75.9%
EWMA[f]	63.908	24.061	0.630	0.630	78.7%
REDI[g]	67.470	25.753	0.520	0.520	77.1%

[a]Coupled acute:chronic workload ratio.
[b]Uncoupled acute:chronic workload ratio.
[c]Weekly ratio of workload change (%).
[d]Monotony.
[e]Standard deviation of weekly workload change.
[f]Exponentially weighted moving average.
[g]Robust exponential decreasing index.

TABLE 7 Multilayer perceptron results with a 10-day delay.

	Cross-entropy error		AUC		Accuracy
	Training set	Test set	Injury	Non-injury	
ACWR[a]	55.991	25.719	0.789	0.789	75.0%
UnACWR[b]	51.034	24.041	0.785	0.785	80.8%
Diff[c]	59.327	21.722	0.581	0.581	73.7%
Monotony[d]	69.811	26.063	0.553	0.553	79.2%
SD[e]	64.637	32.456	0.516	0.516	76.3%
EWMA[f]	59.171	28.781	0.503	0.503	77.8%
REDI[g]	58.129	28.768	0.659	0.659	73.5%

[a]Coupled acute:chronic workload ratio.
[b]Uncoupled acute:chronic workload ratio.
[c]Weekly ratio of workload change (%).
[d]Monotony.
[e]Standard deviation of weekly workload change.
[f]Exponentially weighted moving average.
[g]Robust exponential decreasing index.

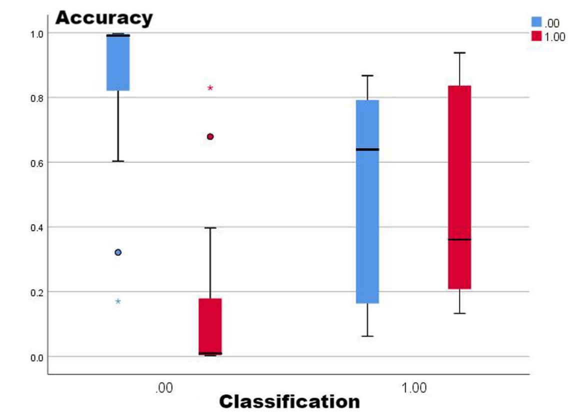

FIGURE 1
Sorted box plot from EMWA without delay.

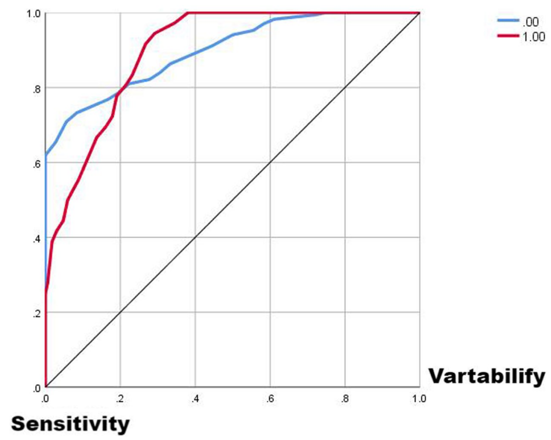

FIGURE 2
ROC curve plot from EMWA without delay.

Combining the performance of AUC and accuracy, the optimal two means are selected for comparison (no-lag EWMA and the 5-day lag weekly ratio of workload change), both of which have good clustering quality and perform well in capturing non-injury samples, as shown in the classification box plot. The 5-day lag weekly rate of change is better than the no-lag EWMA in capturing injury samples; however, the mean value case of the no-lag EWMA performance is slightly better than the 5-day lag weekly rate of change, but affected by the extreme values, resulting in the overall injury sample capture worse than the 5-day lag weekly ratio of workload change. For samples with abnormal load changes, it is possible that the 5-day lag weekly rate of change is more sensitive than the no-lag EWMA, probably due to the fact that EMWA has taken into account the problem of weighting the load of the time series, and still weighted the samples with abnormal load changes, reducing its sensitivity (13). However, such a practical situation often involves low injury risk, and coaches can completely combine the actual situation to make a judgment, thus for the abnormal performance of the no-lag EWMA at extreme values, this study is considered to be negligible.

Comparing the two ROC curves, the no-lag EWMA outperforms the 5-day lag weekly ratio of workload change in both the non-injury sample and the injury capture, but both perform better. Comparing the gain and benefit plots of the two they are similar in the non-injury samples, but in the injury samples, the no-lag EWMA shows better gain and benefit performance, the no-lag EWMA has already reached 100% gain compared to the no-modeled case in 50% of the data, while the 5-day lag weekly ratio of workload change has only reached 100% gain compared to the no-modeled case in 80% of the data. The no-lag EWMA achieves a 4.0-fold benefit over the no-model case at 10% of the data, while the 5-day lag weekly ratio of workload change is lower than the 4.0-fold benefit over the no-model case at 10% of the data, and at 50% of the data, the no-lag EWMA maintains a 2.0-fold benefit, while the 5-day lag weekly rate of change is already lower than the 2.0-fold benefit.

4 Discussion

Based on previous research, the algorithm that is theoretically most sensitive to injury risk is REDI (13). This is because the load accumulation method with natural logarithmic weighting, which REDI uses, is superior to the load accumulation method used by EWMA. Moreover, REDI also considers the issue of missing data. By correlating the next week's injury with the load of the current week at different time lags, the correlation between injury and load can be increased (12). This is because the occurrence of injury is delayed and there is an incubation period. Therefore, this study hypothesizes that correlating the next week's injury with the load of the current week (with a 5-day lag) using REDI's ACWR calculation method would yield the highest correlation between injury and load. However, the research results of this study are different from the expected hypothesis.

Among the different models (logistic regression vs. neural network) at different time lags (no lag vs. 5-day lag vs. 10-day lag), EWMA without any time lag was found to be the most sensitive indicator for detecting injury risk. According to the results of logistic regression, only EWMA and REDI without any time lag showed ideal classification performance ($Accuracy_{EWMA\&REDI} = 84.4\%$, $p < 0.001$). The results of the neural network showed that EWMA and REDI without any time lag exhibited ideal classification performance ($Accuracy_{EWMA} = 90.0\%$, $Accuracy_{REDI} = 87.2\%$, $ROC_{EWMA} = 0.899$, $ROC_{REDI} = 0.721$). These results are consistent with previous studies. Under the same model, the results without any time lag were superior to those with other time lags (5-day lag and 10-day lag), which differs from previous research. We speculate that this discrepancy may be due to project differences. There were also differences between the results of different models (logistic regression vs. neural network). A common finding is that the accuracy of model classification decreases with longer time lags. However, the ACWR calculation method differs at different time lag nodes. Additionally, the results of logistic regression were more stable, while the neural network showed the best performance without any time lag, but its performance was worse than logistic regression at other time lag nodes. The reason for this may be related to the proportion of injuries, which will be explained in detail later in the text.

From Figures 1–5, it can be observed that the two models with the best injury classification performance have extremely high accuracy in classifying non-injury cases, but the classification accuracy for injury cases is between 30 and 40%. The accuracy of EWMA without

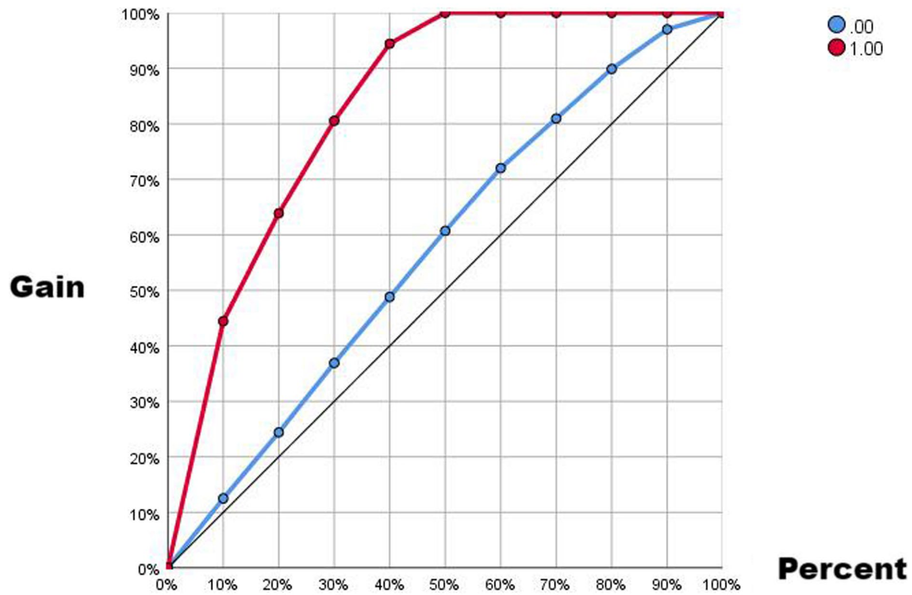

FIGURE 3
Gain plot from EMWA without delay.

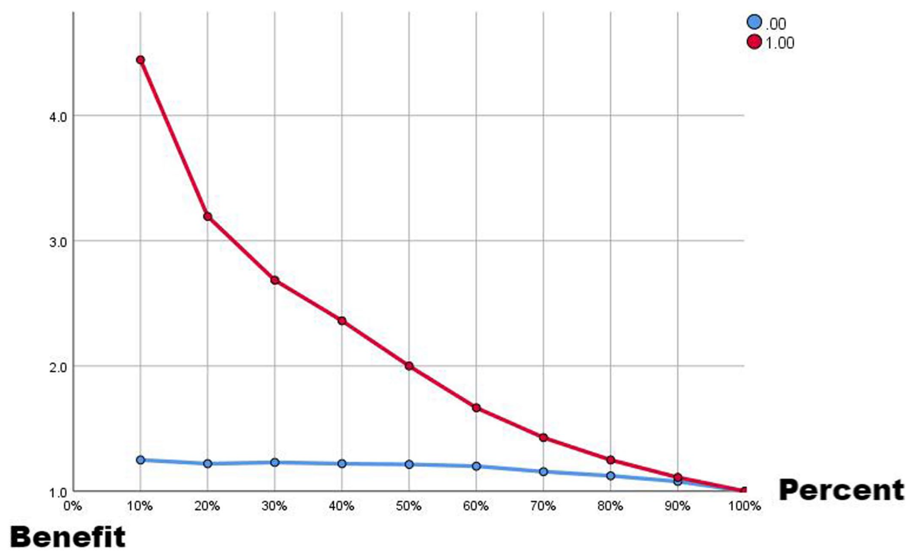

FIGURE 4
Benefit plot from EMWA without delay.

any time lag is slightly better than that with a 5-day lag. This result indicates that curling athletes do indeed have a problem of load accumulation in their training, which needs to be considered in load monitoring (Figure 6).

4.1 Data bias

Logistic regression and generalized estimating equations have been used in most of the studies on ACWR, and quadratic regression and generalized linear models have been used in a few studies. In the analysis of damage classification, the significant challenges are damage data bias, a large amount of non-damage data, and a small amount of damage data. This puts higher demands on data analysis and requires that the analysis method captures the features of damaged data more accurately. In conjunction with the findings of this study, the results of the neural network were overall better than those of logistic regression, supporting the results that the adoption of deep learning for deep data mining and capturing data features in the field of sports science has been a driving force for progress in practice (17) (Figure 7).

4.2 Workload accumulation

The problem of load time series superposition, the effect of past loads on current loads, has been neglected in past load monitoring studies. Although it is not necessary to take this into account in some load monitoring tools, especially immediate state evaluation, it is necessary to take this into account in the use of sRPE. The results of this study support that EMWA's load-weighting approach is the optimal result (11). Moussa proposed the REDI approach to solving the problem of missing load time series (rest day loads are recorded as 0 A.U.) (13) and argued that REDI would outperform the EWMA in the presence of missing data but the results of the present study do not support this view. Despite the presence of missing data, the performance of EWMA with different lags outperforms the performance of REDI (Figure 8).

4.3 Hysteresis period

Previous researchers have argued that there is a lag in the emergence of load (12), and it is true that for the weekly ratio of workload change, the consideration of the lag period is valuable, and

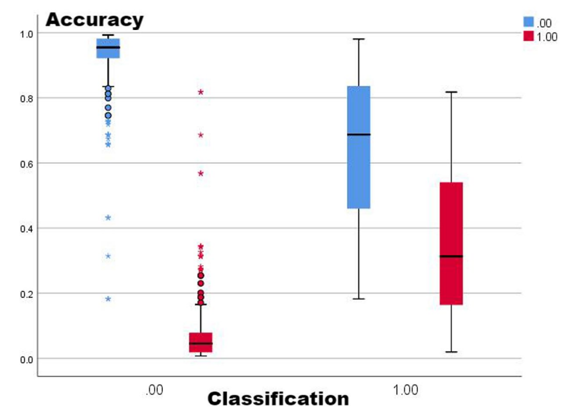

FIGURE 5
Sorted box plot from Diff with a 5-day delay.

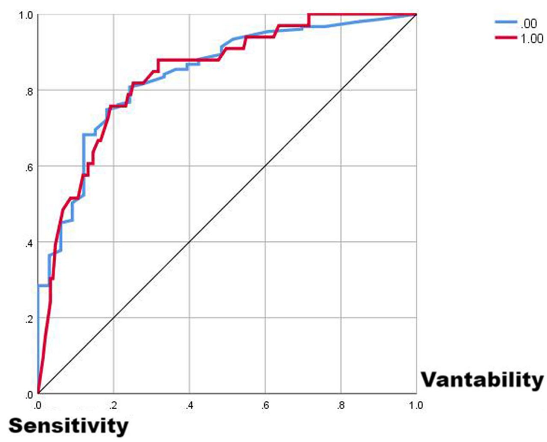

FIGURE 6
ROC curve plot from Diff with a 5-day delay.

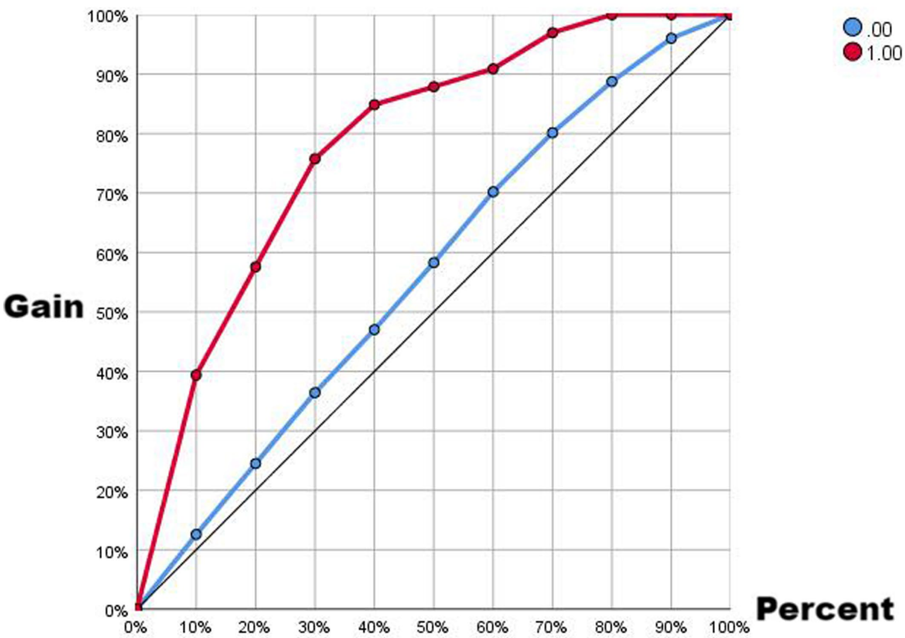

FIGURE 7
Gain plot from Diff with a 5-day delay.

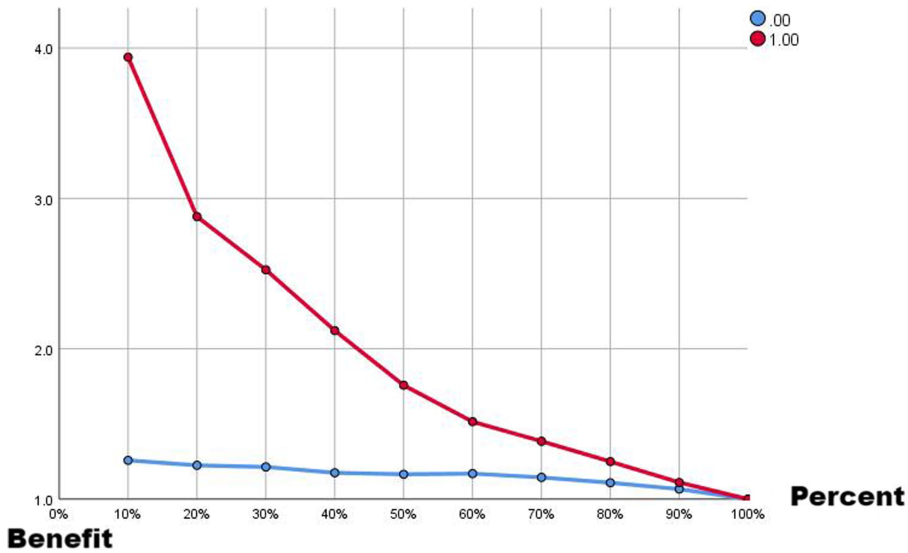

FIGURE 8
Benefit plot from Diff with a 5-day delay.

among no lag, 5-day lag, and 10-day lag, a weekly ratio of workload change with a 5-day lag performs the best, but the results of the analysis of other means with no lag were better than the results of the 5-day and 10-day lag. Therefore, for the other means, the risk of injury is studied in the relationship with loading before, there is no need to consider the lag period.

5 Conclusion

In capturing load risk by sRPE, EWMA without delay is a more sensitive indicator for detecting damage risk, which has practical significance by taking into account the load time series weights and the lag period of damage occurrence. It is suggested that the time decay of load time series weights and the lag time of damage occurrence should be considered according to the actual situation when sRPE is used for load monitoring in the future.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: the datasets used or analyzed during the current study are available from the corresponding authors on reasonable request. Requests to access these datasets should be directed to wujunqi567@foxmail.com.

Ethics statement

The studies involving humans were approved by Sport Science Experiment Ethics Committee of Beijing Sport University, No. 2023283H. 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

JW: Conceptualization, Formal analysis, Investigation, Methodology, Software, Writing – original draft. FZ: Data curation, Supervision, Writing – original draft. CL: Conceptualization, Resources, Supervision, Writing – review & editing.

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Music influences performance without increasing perceived exertion during high-intensity rowing intervals: a cross-over design study

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Objectives: This study assessed how exposure to slow (SBM) versus fast beat music (FBM) during high-intensity rowing intervals affects performance, heart rate (HR), lactate levels, relative perceived exertion (RPE), and recovery.

Methods: The A/B crossover design involved 21 participants performing 5 × 500 m rowing intervals under two conditions: FBM and SBM. Primary endpoint was the difference in total rowing time. Secondary endpoints included average HR, average RPE as well as rowing interval times, RPE, and HR per interval. For exploratory purpose, HR and lactate drop during the initial 5 min post completion was analyzed.

Results: Listening to FBM resulted in significantly shorter total rowing times ($p = 0.009$, $r_B = 0.59$), especially during the 1st interval. The 1st interval was also significantly faster than intervals 2–5 ($p < 0.001$), with the greatest performance drop between the 1st and 2nd interval during FBM. Average HR was significantly lower when listening to SBM ($p = 0.03$, $r_B = 0.48$), while average RPE showed no significant difference ($p = 0.47$, $r_B = 0.02$). Lactate values after interval 5 were significantly lower in SBM ($p = 0.05$, $r_B = 0.41$), but no significant difference was found for lactate drop ($p = 0.21$, $r_B = 0.21$). However, participants exhibited a higher HR drop rate with SBM ($p = 0.05$, $r_B = 0.42$).

Conclusion: FBM improved performance without increasing RPE, while SBM proved superior for recovery. Systematic customization of music based on intended training stimuli holds broad potential for the competitive sports, fitness, and health sector.

KEYWORDS

self-selected music, heart rate, recovery, pacing, drop in performance

1 Introduction

Music is a universal cultural phenomenon that elicits a multitude of physiological and psychological responses. Previous research has concluded that the underlying mechanisms are related to the modulation of brain activity of cortical systems involved in the hypothalamic–pituitary–adrenal axis, autonomic regulation, movement control, emotional-behavioral control, attention, and automatic evaluation (Koelsch, 2014). As a result, simply listening to music can lead to changes in respiration, heart rate (HR), heart rate variability, and blood pressure. Moreover, music has been found to improve physical performance, mask fatigue, increase arousal, regulate emotions, and benefit physiological efficiency in physical activities (North et al., 2000; Greasley and Lamont, 2006; Simpson and Karageorghis, 2006; Saarikallio and Erkkilä, 2007; Mohammadzadeh et al., 2008; Karageorghis et al., 2009; Saarikallio, 2011; Karageorghis and Priest, 2012a,b; Moore, 2013; Uhlig et al., 2013; Mclaughlin et al., 2020). Consequently, the influence of music could offer considerable potential in the field of sports to enhance athletes' performance. The scientific literature provides emerging evidence towards this notion, whereby several parameters such as tempo, personal preferences, time of music exposure as well as the exercise intensity appear to influence the effect music has during exercise.

For instance, Crust showed that listening to music positively affects isometric muscular endurance. However, this effect only occurred if the music was listened throughout the exercise whereas being exposed to music solely before exercise did not (Crust, 2004). Positive effects on peak and mean power when listening to music during exercise compared to no music were also found by Stork et al. for sprint interval sessions on a cycling ergometer (4 sets of 30 seconds [sec] at maximum effort) whereas no differences between conditions were found for relative perceived exertion (RPE) (Stork et al., 2015). Improved performance was confirmed by Rendi et al. who tested the influence of fast beat (FBM), slow beat (SBM), and no music during 500 meter [m] rowing sprints. In this case, it was noteworthy that despite a shorter time to completion when listening to FBM, RPE did not differ compared to the other conditions. When comparing the results of Rendi et al. to other studies, it needs to be considered that the music was selected by the researchers and the participants were experienced rowers (Rendi et al., 2008). Similarly, Wu et al. showed that the time to perceived fatigue extended when listening to SBM and FBM compared to no music (Wu et al., 2022). Besides tempo and time of exposition, personal music preference seems to be another important factor (Ballmann et al., 2021). In this regard, Nixon et al. analyzed how listening to preferred compared to non-preferred music volume affects time to completion, HR, RPE, and motivation during a 2000 m rowing time trial. In contrast to the above-stated study of Rendi et al., time to completion did not differ between conditions. Nevertheless, RPE was significantly lower and motivation higher when listening to preferred music volume (Rendi et al., 2008; Nixon et al., 2022). Karow et al. also compared the effects of preferred, non-preferred, and no music in a 2000 m rowing time trial. Although the music was only played during the warm-up prior the actual time trial, relative power output and HR were higher while trial time was lower in the preferred music condition when compared to the other conditions whereas no differences occurred for RPE (Karow et al., 2020). Karageorghis and Priest concluded in a review that music could reduce RPE by ~10% during physical tasks. However, the authors stated that this effect mainly occurs at low to moderate intensities but is not pronounced in activities beyond the anaerobic threshold, respectively, high-intensity training (Karageorghis and Priest, 2012a,b). It was further hypothesized that external sensory stimuli could not be processed effectively during high-intensity exercise as the overwhelming physiological stimuli already overtax the capacity of the afferent nervous system (Rejeski, 1985; Hutchinson and Tenenbaum, 2007; Karageorghis and Priest, 2012a,b). In a systematic review of Marques et al. analyzing specifically the influence of music on high-intensity exercise, it was concluded that music does not reduce RPE (Marques et al., 2024).

To summarize, despite emerging evidence regarding the positive effects of music applied during exercise, scientific literature is still inconclusive and partly contradictory, especially in terms of high-intensity activities. However, based on the findings of Marques et al., the chances of benefiting from positive effects of music during high-intensity exercise could be increased by applying high tempo, preferred, motivational music and play it over the course of several high-intensity bouts (Marques et al., 2024). A form of exercise that is performed at high intensities in different fitness domains is rowing (Glassman, 2020; Bergmann, 2024). However, previous research investigating the influence of music during rowing did not adhere to the guidelines recently stated by Marques et al. (2024). Subsequently, the aim of the present study was to investigate how exposition to SBM compared to FBM which is self-selected and played during high-intensity rowing interval protocol affects performance, physiological parameters, RPE, and recovery.

2 Materials and methods

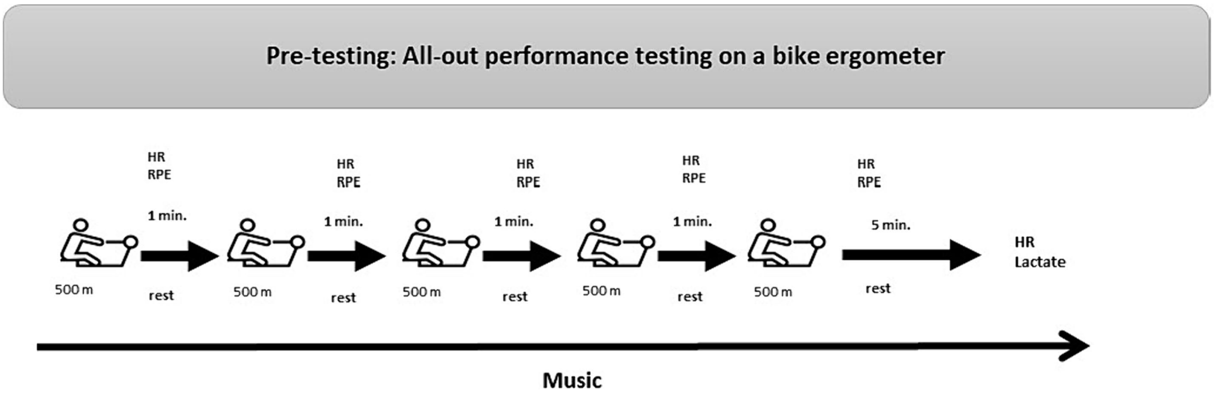
2.1 Experimental design

This study followed an A/B crossover design in which the participants performed a 5 × 500 m rowing ergometer test under different music conditions (FBM and SBM) that varied in music tempo (beats per minute [bpm]). Before the actual test, a pre-test was carried out on a bicycle ergometer to ensure an even group allocation of participants according to their physical fitness. To achieve a power of 80% on a one-sided 5% significance level in the primary endpoint, a sample size of 22 was calculated by *a priori* power analysis with G*Power (Faul et al., 2007). The study protocol is displayed in Figure 1.

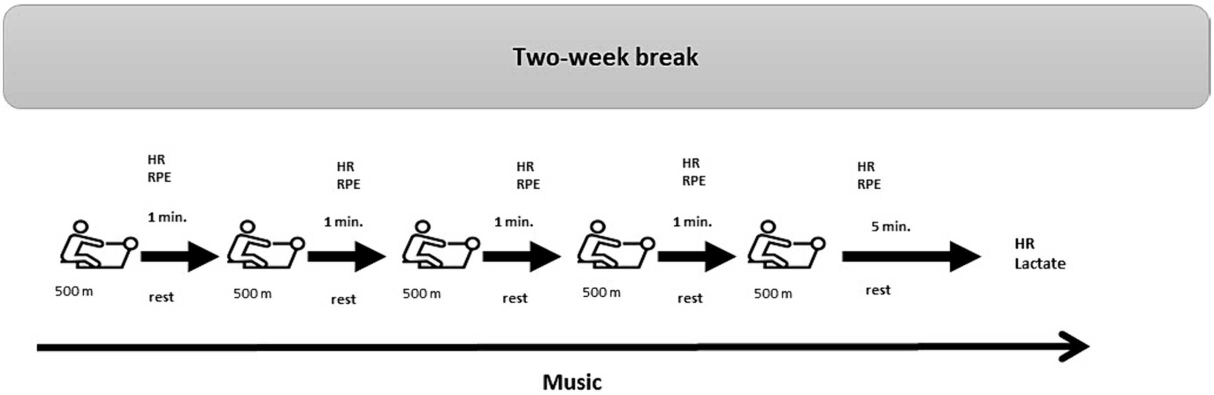
2.2 Procedure

2.2.1 Pre-test

Before the testing on the rowing ergometer, a pre-testing was conducted at the University of the Bundeswehr Munich (UniBw M). During the pre-testing, demographic data and preferred music style were assessed. Additionally, an all-out test on an Excalibur sport bike ergometer (Lode BV, Groningen, Netherlands) was conducted to allocate participants evenly to groups A and B based on their physical performance abilities. The test protocol started at 70 watts [W] and was increased by 30 W every 2 min [min] until a maximum of 400 W. The participants were informed to cycle permanently at 60 to 80 turns/min. Otherwise, the testing was terminated within 10 sec after dropping below the threshold. Shortly before switching to the



Groups	Week 1
Group A	Fast beat music
Group B	Slow beat music



Groups	Week 2
Group B	Fast beat music
Group A	Slow beat music

FIGURE 1
Study design. HR, heart rate; min, minutes; m, meters; RPE, relative perceived exertion.

next higher stage, HR, blood lactate, and RPE were recorded. After quitting due to maximum exertion or reaching 400 W, the participants cycled another 5 min at 50 W for recovery.

2.2.2 Music characteristics

In the literature focusing on music in physical activity, music with <120 bpm is considered slow and > 120 bpm fast (Terry et al., 2020). This was taken into account for the present study to categorize the music conditions. Two music conditions were chosen: (A) FBM (mean (M) = 134.2; standard deviation (SD) = 33.2 bpm) and (B) SBM (*M* = 96.9; SD = 16.8 bpm). Based on the given mean tempo of each track in bpm, the mean tempo of the SBM and FBM condition was calculated. The FBM condition was divided into 2 music sets according to the participant's preferences. In addition to music tempo, music tracks were selected based on the following principles: (A) the FBM tracks had a cheerful music style and should induce positive emotions, (B) the SBM tracks had no lyrics and were marketed as "Yoga" or "relaxing" music by the streaming provider. The music was played by use of a smartphone and Bluetooth speakers at a volume of 60–65 decibel [dB]. Participants were instructed to not listen to any music for at least 1 hour [h] before the test. The music was started when the participants began their warm-up and then played throughout the entire protocol, including rest periods and cool-down.

2.2.3 5 × 500 m test

The actual testing took place at the military affiliation CrossFit Kokoro® and consisted of 2 test sessions with a 2-week break in between. Participants were instructed to stop eating and to not listen to any music at least 1 h before the sessions. In the 1st test session, group A rowed while listening to FBM and group B to SBM. During the 2nd session, music conditions were interchanged. Both sessions followed the same rowing protocol. As recommended for high-intensity exercise testing, a rowing interval protocol was chosen that allowed participants to reach their limit of tolerance in about 10 min (Porszasz et al., 2003). According to previous research including physically active adults ($N = 17$, Age: 29 (SD = 5) years), 500 m rowing on an ergometer takes 112.1 (SD = 7.9) and 113.2 (SD = 8.9) sec being in a pre-exhausted state (Silva de Souza et al., 2024). Therefore, 5 × 500 m intervals were determined as a test that physically active sports science students would be able to carry out.

The protocol started with a guided warm-up. Thereafter, participants were instructed to row 5 × 500 m intervals as fast as possible at resistance level 6 (Model D Indoor Rower, Concept2 Germany GmbH, Hamburg, Germany). Between the intervals, participants were given 1 min rest. After each 500 m interval, interval rowing time [sec], HR [bpm] (Polar H10, Polar Electro GmbH Deutschland, Büttelborn, Germany), and RPE were recorded. RPE was assessed with the Borg scale, which allows the expression of perceived exertion on a scale ranging from 6 to 20, whereby 6 represents the lowest and 20 the highest perceived exertion (Löllgen, 2004). HR was measured again 5 min after completion of the last interval. Blood lactate (Lactate Scout +, EKF Diagnostics, Barleben, Germany) was taken after completion of the rowing intervals (end lactate [mmol/L]) and again 5 min later (recovery lactate [mmol/L]). The total rowing time [sec] was calculated by summing up the rowing interval times of the 5 intervals. Based on HR and RPE measures of each interval, the average HR and RPE were calculated. HR drop [%] and lactate drop [%] were calculated to give an estimate for the recovery during the first 5 min after completion of the last interval. The study protocol is displayed in Figure 1.

The difference in total rowing time between the FBM and SBM conditions was the primary endpoint of this study. Secondary endpoints were differences in average HR and average RPE and in rowing interval times, RPE, and HR per interval between the FBM and SBM conditions. End lactate, recovery lactate, and the drop of HR and lactate during the first 5 min after completion of the rowing intervals were analyzed for exploratory reasons.

2.3 Participants

The study included healthy officers and officer candidates of the Federal German Armed Forces who were at least 18 years old studying sports science at the UniBw M. To achieve a power of 80% on a one-sided 5% significance level in the primary endpoint, a sample size of 22 was calculated by *a priori* power analysis with G*Power (Faul et al., 2007). In total, 26 participants signed up for the study, of which 5 participants were excluded (19%). Although 21 data sets were less than the calculated sample size needed, the post-hoc power analysis revealed that the power was still sufficient (0.81). After the pre-testing, participants were allocated to groups A ($N = 10$) and B ($N = 11$).

Of these 21 participants, 14% were female, and 86% were male. Their age ranged from 19 to 31 years. On average, the participants were 22.1 (SD = 2.7) years old, 180 (SD = 7.7) centimeters [cm] tall, weighed 82.1 (SD = 11.71) kilograms [kg], and did 3.3 (SD = 1.6) hours of endurance exercise per week. The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the UniBw M, Germany (06/04/2018). The guidelines of the European General Data Protection Regulation have been implemented. From all participants, consent was obtained before participation in the study.

2.4 Statistical analysis

Differences in total rowing time, average RPE, average HR, end lactate, HR recovery, and lactate recovery between the FBM and SBM conditions were analyzed with the Wilcoxon signed-rank test as the assumptions for normality were violated. Normal distribution was analyzed with Q-Q-plots and Shapiro–Wilk test. Within-group 5 × 2 repeated measures analyses of variances (rmANOVA) were conducted to analyze the change of rowing times, RPE, and HR per interval between the FBM and SBM condition (Blanca et al., 2017). The homogeneity of groups was tested via Levene's test. Greenhouse–Geisser correction was applied if the assumption of sphericity was violated. Bonferroni correction was used for post-hoc tests to control for multiple testing. Statistical significance was set at $p \leq 0.05$. Effect sizes of the rmANOVA are given in partial η (Greasley and Lamont, 2006). Data analysis was conducted with Excel 2019 (Microsoft, Redmond, United States) and JASP Version 0.16.4 (JASP, Amsterdam, Netherlands).

3 Results

3.1 Primary endpoint

The mean total rowing time when listening to SBM was 593 (SD = 74.3) sec. With a mean total rowing time of 572.9 (SD = 57.9) sec while listening to FBM, a significant difference in performance between music conditions was found ($p = 0.009$, $r_B = 0.59$). Additional information is presented in Table 1.

3.2 Secondary endpoints

Further analysis of rowing interval times via 5 × 2 rmANOVA with Greenhouse–Geisser correction revealed that there was no interaction effect ($p = 0.45$, $\eta_p^2 = 0.04$). Furthermore, no main effect for the factor *music* was found ($p = 0.063$, $\eta_p^2 = 0.16$). However, a significant main effect occurred for the factor *interval* ($p < 0.001$, $\eta_p^2 = 0.49$). Post-hoc tests with Bonferroni correction showed that the 1st interval was significantly faster than the intervals 2–5 ($p < 0.001$). The greatest difference in rowing times between the FBM and SBM condition was found for the 1st interval. The largest drop in performance occurred during the FBM condition between the 1st and

TABLE 1 Primary, secondary, and exploratory outcomes for the fast and slow beat music condition.

		Median	Mean	SD	Min	Max	p
Total time (sec)	SBM	583.00	593.05	74.33	484.00	772.00	0.009
	FBM	555.00	572.86	57.88	490.00	707.00	
Average HR (bpm)	SBM	177.20	173.31	14.30	125.00	195.20	0.03
	FBM	176.80	177.45	9.7	163.20	197.60	
Average RPE (score)	SBM	14.00	14.40	2.06	11.00	17.20	0.47
	FBM	14.60	14.50	1.55	12.20	16.80	
End lactate (mmol/L)	SBM	8.70	8.1	3.30	1.60	14.30	0.05
	FBM	10.00	9.21	3.01	3.80	13.90	
Recovery lactate (mmol/L)	SBM	8.50	7.79	2.99	1.60	11.90	0.01
	FBM	9.80	9.08	2.99	4.10	13.80	
HR drop (%)	SBM	41.62	40.21	6.76	19.16	49.46	0.05
	FBM	38.98	37.62	5.09	27.61	45.11	
Lactate drop (%)	SBM	2.3	1.91	12.59	−29.76	24.14	0.21
	FBM	−0.81	0.11	16.15	−30.19	28.06	

bpm, beats per minute; sec, seconds; mmol/L, millimoles per liter; FBM, fast beat music; SBM, slow beat music; HR, Heart Rate; SD, standard deviation; Min, Minimum; Max, Maximum; RPE, relative perceived exertion.

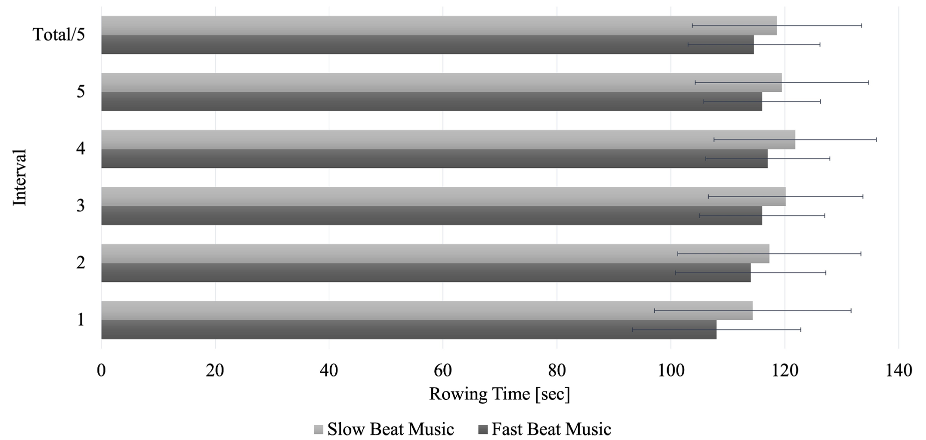


FIGURE 2
Rowing times for each interval split for the fast and slow beat music conditions. The upper bar "Total/5" shows the average rowing time over all 5 intervals for both conditions. sec, seconds.

2nd interval. Total rowing times as well as times per interval are displayed in Figure 2.

Mean average HR was 173.3 (SD = 14.3) bpm in the SBM condition and 177.5 (SD = 9.7) bpm in the FBM condition. This resulted in a significant difference in average HR between conditions ($p = 0.03$, $r_B = 0.48$). Looking at the 5 × 2 rmANOVA with Greenhouse–Geisser correction, there was no interaction between the factors interval and music ($p = 0.44$, $\eta_p^2 = 0.04$). Again, no significant main effect was found for the factor *music* ($p = 0.10$, $\eta_p^2 = 0.13$), but for the factor *interval* ($p < 0.001$, $\eta_p^2 = 0.83$). A post-hoc test with Bonferroni correction showed that in accordance with the rowing times per interval, the HR during the 1st interval was significantly higher than for the intervals 2–5 ($p < 0.001$). HR over the course of the 5 × 500 m rowing intervals are presented in Figure 3.

In contrast to a significant higher average HR in the FBM condition, no significant difference in average RPE between groups was found ($p = 0.47$, $r_B = 0.02$). The interaction effect was also not significant ($p = 0.97$, $\eta_p^2 = 0.01$). A significant main effect occurred for the factor *interval* ($p < 0.001$, $\eta_p^2 = 0.89$), but not for *music* ($p = 0.73$, $\eta_p^2 = 0.01$). Post-hoc tests with Bonferroni correction showed that the RPE in the 1st interval was significantly lower than the RPE in the intervals 2–5 ($p < 0.001$). RPE over the course of the 5 × 500 m rowing intervals are presented in Figure 4.

3.3 Exploratory endpoints

The average lactate values after completion of interval 5 were 8.1 (SD = 3.3) mmol/L in the SBM and 9.2 (SD = 3) mmol/L in the

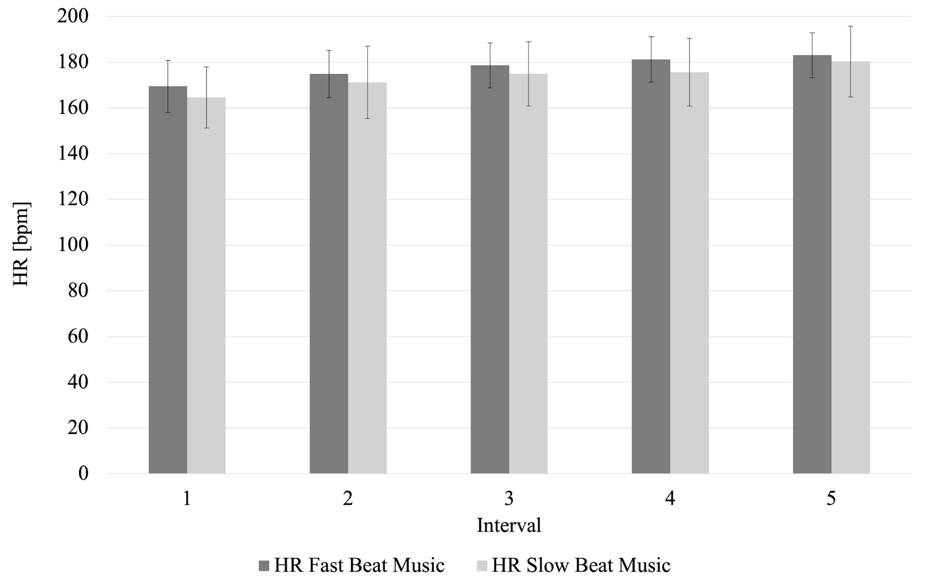


FIGURE 3
Relative perceived exertion over the course of the rowing intervals for the fast and slow beat music condition. HR Fast Beat Music, heart rate during fast beat music; HR Slow Beat Music, heart rate during slow beat music.

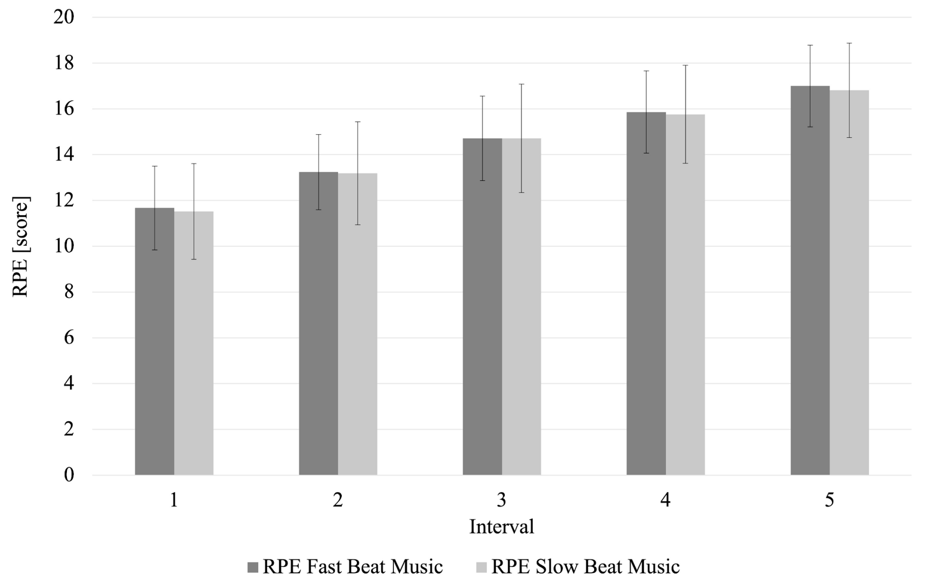


FIGURE 4
Heart rate and relative perceived exertion over the course of the rowing intervals for the fast and slow beat music condition. RPE Fast Beat Music, relative perceived exertion during fast beat music; RPE Slow Beat Music, relative perceived exertion during slow beat music.

FBM condition resulting in a significant difference between conditions ($p = 0.05$, $r_B = 0.41$). Lactate values 5 min after completion were 7.8 mmol/L (SD = 3) and 9.1 mmol/L (SD = 3) in the SBM and FBM condition. The blood lactate drop did not differ significantly between conditions ($p = 0.21$, $r_B = 0.21$). Contrary, the HR drop differed significantly between the SBM and FBM condition with a higher drop rate in the SBM condition ($p = 0.05$, $r_B = 0.42$). HR and lactate drop rates can be found in Table 1.

4 Discussion

The aim of the present study was to examine how exposition to SBM and FBM influences performance, physiological parameters, RPE, and recovery during high-intensity rowing intervals. In terms of performance, a positive effect of FBM was found compared to SBM. This was evident in each of the 5 intervals by means of shorter times to completion. This generally supports the notion of

Karageorghis and Priest (2012a,b) that carefully selected music leads to beneficial ergogenic effects.

Indeed, comparisons with earlier studies should be treated with caution due to the small number of studies investigating high-intensity interval exercise and differing research designs (Marques et al., 2024). Nevertheless, some parallels can be drawn with a study of Rendi et al. ($N = 22$) who found that listening to FBM leads to greater performance during high-intensity rowing compared to SBM or no music. However, in the study of Rendi et al. participants performed only one 500 m sprint per music condition (FBM, SBM, no music) instead of multiple intervals (Rendi et al., 2008). Therefore, the results of the study conducted by Rendi et al. could at most be related to the results of the 1st interval of the present study. Interestingly, the difference in performance between FBM and SBM was most pronounced in the 1st interval. Apparently, the FBM could have acted as a more effective external psychological stimulus compared to the SBM that motivated the participants to be more willing to exercise hard.

In a qualitative study ($N = 13$) on the effects and characteristics of music accompanying exercise, Priest and Karageorghis showed that even sheer anticipation of a motivational music segment in the absence of music could have a stimulating effect (Priest and Karageorghis, 2008; Karageorghis and Priest, 2012a,b). In the current study, the participants knew whether the FBM or SBM would be played during the test. Therefore, they may have already been primed for high performance when expecting the motivational FBM. Because the influence of music is most evident when the physical task is self-paced, the effects observed in the present study could have been further amplified (Karageorghis and Priest, 2012a,b).

Under both music conditions, the 1st rowing interval was the fastest. Thereafter, times to completion increased until the 4th interval which indicates that the fatigue accumulated over time. Nevertheless, both groups were able to motivate themselves towards slightly shorter times to completion in the 5th compared to the 4th interval. Looking at completion times, it is worth noting that although the FBM was superior in terms of performance, especially in the 1st interval, participants also experienced the greatest drop in performance in the FBM condition, namely between the 1st and 2nd interval. Hutchinson et al. made a similar observation since they found that the energizing effects of music were strongest at the start of a physical task whereas this effect diminished over time (Hutchinson et al., 2011). Based on these findings, it is to assume that particularly FBM could increase the risk for over pacing which might impair the overall performance of athletes when performing multiple intervals or longer duration exercise.

Consequently, greater performance in the FBM condition was accompanied by higher mean HR and mean end lactate values, indicating that the participants were actually exerting themselves more physiologically compared to the SBM condition. However, RPE did not differ between conditions. This appears to contradict the theory that external sensory stimuli cannot be processed effectively during high-intensity exercise as the overwhelming physiological stimuli already overtax the capacity of the afferent nervous system (Rejeski, 1985; Hutchinson and Tenenbaum, 2007; Karageorghis and Priest, 2012a,b). Nevertheless, the FBM still seemed to distract participants from the higher physiological exertion which was also observed in previous research (Rendi et al., 2008). Following the theory of limited processing capacity, it could be assumed that rowing indoors on an ergometer is not that taxing for the afferent nervous system due to the low technical demands of the exercise as well as minimal external (e.g., changing scenery, people, odours) and internal (e.g., kinaesthetic) stimuli to be processed when compared to translational movements performed outdoors. Furthermore, while rowing 500 m at high intensities is indeed a demanding physical task, participants did not experience the same level of physiological fatigue over the course of an interval. Instead, physiological fatigue built up over the course of each interval and declined again between the intervals. As a result, for a certain period of time during each interval, physiological feedback signals might have been low enough for the participants to still profit from the ergogenic and psychophysical effects of the FBM. Additionally, the faster time to the completion in the 5th compared to the 4th interval further indicates that participants did not reach volitional fatigue, at least in the intervals 1–4. This must be taken into account in order to compare the results of the present study with those of previous investigations, in which the participants exercised at high intensities as well, but had to maintain a high intensity until volitional exhaustion (Eliakim et al., 2012; Maddigan et al., 2019).

In terms of recovery, results of the current study suggest that listening to SBM facilitates HR drop after high-intensity exercise. This could be either attributed to a reduction in physiological arousal by the SBM or the inhibition of FBM on HR recovery following high-intensity exercise (Karageorghis et al., 2018; de Witte et al., 2020; Terry et al., 2020).

In the present study, the strategies Marques et al. recommended in a recent review to benefit performance, RPE, and recovery during high-intensity exercise were applied (Marques et al., 2024). This included the application of self-selected, preferred motivational music that was played throughout the complete protocol consisting of several high-intensity bouts. The novelty of this study lies in the application of these strategies during high-intensity rowing ergometer intervals with solely the music tempo being varied. Contrastingly, earlier studies usually carried out cycle-based tests with shorter intervals (Stork et al., 2015; Maddigan et al., 2019; Stork et al., 2019; Marques et al., 2022). Studies using a rowing ergometer on the other hand did not set up high-intensity protocols with multiple bouts (Rendi et al., 2008; Karow et al., 2020). Accordingly, the research design applied in the present study expanded the current state of research. It was shown that FBM has a positive effect on performance without increasing RPE during high-intensity rowing ergometer tests compared to SBM, even if several intervals had to be completed. The results of the present study further suggested that the positive effects of FBM on performance and RPE can also be observed during self-paced high-intensity exercise when the interval lengths exceed the duration investigated in previous studies (Stork et al., 2015; Maddigan et al., 2019; Stork et al., 2019; Marques et al., 2022). As this study additionally examined the recovery phase after the last interval, it was possible to extend the knowledge regarding music tempo on recovery following high-intensity bouts.

Some limitations should be considered when interpreting the results of the current study. First, we did not include a no-music condition, which makes it difficult to estimate the effect of music in general on the parameters assessed. In addition, this would allow for more in-depth comparisons of the present study with previous ones. While few studies explicitly compared FBM with SBM, several studies investigated the effects of FBM versus no music during high-intensity exercise (Pujol and Langenfeld, 1999; Maddigan et al., 2019). Further, the participants were not homogeneous in terms of their level of training, which should be taken into account, as the benefit of music differs depending on training status (Brownley et al., 1995; Mohammadzadeh et al., 2008; Terry et al., 2020). Additionally, it should be noted that albeit the exercise chosen was rowing on the ergometer, the participants were not rowers but physically active sport science students. Therefore, the results can not necessarily be generalized to other groups of people. Lastly, blood lactate was not measured after each interval, although this would have provided valuable insight regarding the interpretation of physiological fatigue over time. According the findings of this study as well as the mentioned limitations, it is recommended to integrate a no-music condition in future studies. Furthermore, research should consider including physically inactive adults as well as recreational or professional rowers. It is further recommended to investigate different high-intensity protocols and measure lactate values after each interval.

In conclusion, FBM should be preferred during high-intensity rowing intervals to improve performance without an elevation in RPE. In contrast, SBM was superior in terms of recovery after exercise completion. Therefore, systematic use of music that is tailored to the intended training stimulus offers broad opportunities for competitive sports as well as the fitness and health sector. However, further research is required to estimate the effects of deliberate manipulation of music in the aforementioned exercise scenarios.

5 Practical applications

Several possible applications with practical relevance for sports and exercise can be derived from the results of the current study. Distinctions must be made between the conditions in which music could be used to induce certain ergogenic and psychophysical effects. Firstly, music could serve as a tool to help athletes performing high-intensity interval training as part of their training to reach the desired state that matches the current training intention. For example, FBM could be applied during high-intensity interval training whereas SBM might profit recovery periods or deload sessions. It is also conceivable that coaches manipulate music if they realize that their athletes are over pacing or underperforming during training sessions. In this way, verbal instructions could be supplemented by an additional subliminal stimulus in the form of FBM or SBM, without the athletes being aware of this. In competition, when athletes can not select their preferred music or when no music is played at all, SBM could still be used during pauses or post intense competition to aid recovery.

Besides competitive sports, there are further possible applications of music in fitness regimes which regularly include high-intensity interval training such as CrossFit© or Hyrox© (Glassman, 2020; Bergmann, 2024). FBM could help participants display greater performance during high-intensity workouts helping them to achieve their health and fitness goals. In CrossFit© as well as Hyrox©, physiological demands are diverse and vary over the course of different training sessions or even within a single session. Therefore, well selected music could prove beneficial (Meier et al., 2022). In case of a 60 min CrossFit© session, SBM could be played during the warm-up to avoid undesired fatigue. FBM could accompany the high-intensity part of the workout to improve performance and training stimuli while simultaneously curbing perceived exertion. During the cool-down, SBM may be used again to aid recovery. Similar music accompaniment would be imaginable for other fitness areas. Since especially untrained individuals are affected by music, such approaches could provide a considerable opportunity to improve the enjoyment of exercise in physically inactive populations to promote exercise participation and adherence (Brownley et al., 1995; Mohammadzadeh et al., 2008). It is recommended to apply the strategies suggested by Marques et al. Marques et al. (2024) if possible.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethics statement

The studies involving humans were approved by Ethics Committee of the University of the Bundeswehr Munich, Germany (06/04/2018). 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

AndS: Data curation, Formal analysis, Visualization, Writing – original draft. TB: Data curation, Formal analysis, Visualization, Writing – original draft. DA: Investigation, Writing – review & editing. PA: Investigation, Writing – review & editing. MF: Methodology, Writing – review & editing. AnnS: Conceptualization, Methodology, 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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Delivering project SCORE in competitive youth sport settings

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Introduction: This study evaluates the effectiveness of the Project SCORE intervention in fostering Positive Youth Development (PYD) within competitive youth sport settings in Portugal. Project SCORE is an online PYD-focused tool developed to assist coaches in promoting the 4Cs—competence, confidence, connection, and character—within their coaching.
Methods: The research involved 13 coaches and 70 youth athletes from football and rowing teams. Methodologically, this study analyzed the pre- and post-Project SCORE intervention data, assessing the perceptions of coaches and athletes towards the development of the 4Cs.
Results: Results indicated significant improvements in athletes' perceptions of 4Cs post-intervention, and among coaches' perceptions, there was a significant improvement in the practice and transfer of life skills. Particularly, coaches showed enhanced abilities in fostering life skills and facilitating the transfer of these skills to competitive environments, although some dimensions like sport climate did not sustain positive changes.
Discussion: The findings highlight the benefits of customized PYD-based programs in competitive youth sports and suggest the need for further research to enhance their widespread and consistent implementation.

KEYWORDS
coach training, coaching, athlete development, youth development, values, competitive sports

1 Introduction

For Positive youth development (PYD) through sport has been used as an approach to enhance sporting experiences and enable young people to become active participants in society (1). PYD deviates from a perspective that views youth as a problem to be solved, an incomplete project unable to satisfy social demands. Instead, focuses on youth's strengths and aims to develop individuals' assets (2). Concerning PYD through sport, some of the most common outcomes that may come as a result of sport-based PYD programming are life skills and the 4Cs (3–5). Participation in sport-based PYD programs has been associated with the development of life skills in youth athletes (6).

Examples of life skills are respect, leadership, and teamwork that can be used in areas outside sport (7, 8). To encourage coaches to foster life skills in sport programs, Bean et al. (7) proposed a life skills implicit-explicit continuum. This continuum highlights how coaches can use a range of strategies, both implicit (e.g., creating a positive climate, building meaningful relationships with athletes) and explicit (e.g., directly teaching life skills and incorporating them into practice). Holt et al. (4) hypothesised that a PYD climate together with an explicit life skill focus may generate better PYD outcomes than a PYD climate alone, suggesting both implicit and explicit strategies have value in coaching practice. On one hand, implicit strategies have proved useful in fostering PYD in certain sports and cultures (9). On the other hand, explicit strategies that include setting life skills as an objective for practice and providing opportunities to develop these skills (e.g., providing a leadership role) have been considered meaningful (10).

With regards to the 4Cs (11, 12), this framework includes four outcomes that should be attained in sport-based PYD programs: (a) competence, (b) confidence, (c) connection, and (d) character. First, competence refers to social, cognitive and motor skill development. Second, confidence connects to feelings of self-worth and self-efficacy. Third, connection is associated to the quality of the relationships established between different actors within the youth sport system (e.g., the coach and athletes). Finally, character represents the ability to respect for rules and norms, as well as present prosocial behaviours towards others. These 4Cs serve as outcomes of quality sport-based PYD programming (12, 13). Taken together, approaches focused on teaching valuable skills can provide valuable characteristics for the development of youth in and outside sport environments and guide sport-based programming (14).

Based on the benefits that a PYD approach can offer and that coaches are one of the most influential actors that impact youth development, various efforts have been made by researchers aiming to assist and educate coaches (15–17). To equip coaches with the necessary skills and competencies to foster PYD and life skills, several efforts have been made to develop PYD-focused coaching education programs (CEPs) [e.g., (10, 18, 19)]. MacDonald and colleagues (18) studied the impact of a PYD-focused CEP on coach behaviours and athlete perceptions within competitive youth sport. The study found that coaches in the intervention group exhibited an increase in PYD-oriented behaviours during the intervention, but these changes were not sustained at the follow-up phase throughout the latter portion of the season. On the other hand, athletes' perceptions of coach PYD behaviour did not show significant changes over time. Although the results suggest that PYD-focused CEPs may influence coach behaviour in the short term, more research is needed to understand how to maintain these changes and foster positive athlete developmental experiences across all types of youth sport programs (recreational and competitive). Other studies have also supported significant changes in variables such as the quality of coach-athlete relationships and life skills teaching as a consequence of PYD-focused CEPs (20, 21).

One PYD-focused CEP that has been used in past research is Project SCORE (19). It's an online tool developed in 2011 by Canadian researchers that aims to assist coaches in fostering PYD (22). Strachan and colleagues (19) developed Project SCORE with the theoretical foundation of the 4C's. Initially, Project SCORE was a self-administered online resource with asynchronous video content. However, researchers have emphasized the need for contextual adaptations based on participants' learning needs, available time, and priority given to PYD (22, 23). Learner-centred approaches have been considered useful in fostering meaningful coach learning (24). To better understand how learner-centred approaches may apply to coach education, according to Paquette and Trudel (25) has pointed to the need to (a) use contents that instigate engagement with practice; (b) ensure a safe and supporting learning environment that respects coaches' needs; (c) define learning outcomes based on coaches' wants and needs; (d) create solid grounds for coaches to become autonomous while searching for knowledge; (e) consider power dynamics and social pressures; and (f) see coach improvements as a pathways to search for novelty and more contextualized knowledge. Hence, Project SCORE may be paired with other approaches towards coach learning and complementary strategies [see (23) for an example].

Conversely, there are some studies that report the ineffectiveness of PYD-focused CEPs. For instance, Camiré and colleagues (10) evaluated the effectiveness of the "Coaching for Life Skills" online training program for high school coaches. For the most part, these coaches were involved in competitive programs. Results showed no significant changes in variables such as coach-athlete relationships. This may be the case due to the fact that competitive youth sport programs place substantial pressures for coaches to increase performance outcomes, which may come at the cost of other developmental outcomes such as life skills. Furthermore, other studies that have examined the effectiveness of PYD-focused CEPs have reached similar findings [e.g., (26)]. MacDonald et al. (18) suggest that PYD-focused CEPs may influence coach behaviour in the short term, although more research is needed to understand how to maintain these changes and foster positive athlete developmental experiences across all types of youth sport programs (recreational and competitive). Therefore, the evidence available on the effectiveness of PYD-focused CEPs targeting coaches in competitive environments is still unclear, which supports the need for more studies associated to this line of inquiry.

Competitive youth sport programs create a complex setting to establish PYD due to the reward system in place and pressures to perform (27, 28). Moving forward, there is the need to examine how PYD-focused CEPs such as Project SCORE can be tailored to fit different socio-cultural contexts and coaching contexts such as competitive youth sport programs. Furthermore, longitudinal designs are needed to analyse how coaches and athletes change their perceptions because of PYD-focused CEPs as well as other environmental factors and pressures (e.g., period of the sport season). Therefore, the present study aims to analyze the impact of Project SCORE on coaches and youth athletes' experiences within two competitive youth sport settings during a sport season.

2 Methods

2.1 Participants

The final number of participants consisted of 13 coaches and 70 athletes. The coaches (7 males, 6 females) were on average 26.2 years old (SD = 7.7). The athletes (15 males, 55 females) were on average 14.1 years old (SD = 2.2). In order to recruit participants, local sport administrators were contacted to share study details within their organization. Potential participants could participate based on the following criteria: (a) they were involved in a local competitive youth sport organization; (b) youth sport participants were between 10 and 17 years old (29); and (c) coaches were interested in using sport as a context for PYD.

The recruiting process resulted in 15 coaches and 81 athletes from football (soccer) and rowing teams. Both sport organizations were involved in competitive contexts and participated in provincial and national level competitions. Although 15 coaches started the study protocol, two coaches left their position during the study process. Out of the 81 athletes, 11 were removed from the analysis because they did not complete the entirety of the data collection. It should be noted that one of the sport organizations who delivered competitive football programs had female teams that were involved in the intervention, which explains the disparity between male and female athletes.

2.2 Materials

2.2.1 Athletes measures

The data was collected using the measures contained within the 4 Cs toolkit (12, 13) to assess athletes' perceptions of connection, confidence, competence, and character.

2.2.1.1 Connection

Connections between coaches and athletes were measured through the Coach-Athlete Relationship Questionnaire [CART-Q; (30)], which consists of an 11-item questionnaire that assesses the dimensions of closeness, commitment, and complementarity using a seven-point Likert scale (1 - strongly disagree and to 7 - strongly agree). Cronbach alpha values were .58 pre intervention and .67 post intervention for commitment, .73 pre and .86 post for closeness and 65 pre and .76 post for the complementarity.

2.2.1.2 Confidence

Confidence was measured with the Trait Robustness of Self-Confidence for Athletes [TROSCI; (31)], which is a seven-item questionnaire that evaluates two dimensions (i.e., robust self-confidence and unstable self-confidence) through a nine-point Likert scale (1 - strongly disagree and to 9 - strongly agree). The Cronbach alpha values were .77 (pre) and .79 (post) for robust self-confidence and .83 (pre) and .86 (post) for unstable self-confidence.

2.2.1.3 Competence

Competence was measured with the Sport-Confidence Inventory [SCI; (32)], a 14-item questionnaire that evaluates three dimensions using a seven-point Likert scale (1 - absolutely not at all and to 7 - totally certain): confidence in physical skills and training; confidence in cognitive efficiency; and confidence in resilience. The Cronbach alpha values for the measure's subscales ranged from .80 to .87 pre intervention and from .73 to .91 post intervention.

2.2.1.4 Character

The Prosocial and Antisocial Behaviour in Sport Scale [PABSS; (33)] is a 20-item questionnaire that assesses the four dimensions of (i) antisocial behaviour towards teammates, (ii) antisocial behaviour towards opponents of the other team, (iii) prosocial behaviour towards teammates, and (iv) prosocial behaviour towards opponents of the other team. This scale uses a five-points Likert scale (1 - never and to 5 - almost always). The Cronbach alpha values for the measure subscales were between .58 and .82 at pre-intervention and between .47 and .69 post-intervention.

2.2.2 Coaches measures

Coaching for life skills. For coach participants, the Portuguese Coaching Life Skills in Sport Questionnaire [P-CLSS-Q; (34)] was used. The scale is a 30-item questionnaire which assesses the five factors of: (i) structuring and facilitating a positive climate in sport, (ii) discussing life skills, (iii) practicing life skills, (iv) discussing the transfer of life skills, and (v) practicing life skills transfer. The scale uses a six-point Likert scale (1 - strongly disagree and to 6 - totally agree) to assess life skills teaching. In the present study, Cronbach alpha values for the measure's subscales were between .80 and .95 at pre-intervention and between .70 and .93 post-intervention.

2.3 Procedure

2.3.1 Prior to data collection

The study was approved as part of a larger project by the ethics committee of a local polytechnic higher education institution (Polytechnic Institute of Santarém, number 072021). Project SCORE (19) was utilized as a resource to help youth sport coaches understand how to infuse the 4Cs in their coaching practice. The following sections describe (i) the pre-intervention phase (initial data collection with coaches and athletes); (ii) implementation of Project SCORE (description of the training); and (iii) the follow-up phase (post intervention data collection).

2.3.2 Pre-intervention phase

Once participants were recruited, coaches and athletes completed the outlined questionnaires before the Project SCORE workshop. For coaches, it took 10–15 min, and for athletes, 15–20 min to fulfil the questionnaires. The questionnaires were completed before or after a team practice, with the primary researcher present to clarify any questions.

2.3.3 Project SCORE implementation

The implementation of Project SCORE involved a co-developed CEP based on a learner-centered approach [e.g., (24)]. In the present study, Project SCORE was delivered by the primary researcher following a learner-centered approach. This ensured a genuine concern towards learners, their needs, and how meaningful learning occurs (35).

The Project SCORE workshop was used to create an environment conducive to meaningful learning and aimed to forge a positive relationship between the coach developer and coaches. The workshop consisted of a two-hour, in-person, CEP. During the workshop, several topics concerning each of the 4Cs were addressed. Therefore, some strategies concerning the 4Cs were presented such as creating opportunities for athletes to plan and lead the warm-up and prompt a discussion with athletes about life skills transfer. In addition to the primary material, additional topics (e.g., generation Z athletes, parent engagement) which emerged organically were discussed. The workshop took place in January 2023 and the coaches implemented the material with their athletes from February to May 2023. Therefore, the implementation process occurred during the competitive period of the season (approximately halfway through their season).

During the implementation phase of Project SCORE content, the primary researcher (who served as the coach developer) was available to coaches to discuss planning, potential strategies, observe practices, and provide feedback. A total of 71 practices were observed throughout the 21-week period of January 2023 and May 2023. Informal meetings between the first author and each coach took place at least once a week depending on their needs ($n = 57$). Coaches could choose to meet either individually or in groups (39 individual meetings and 18 group meetings were held). Each meeting lasted between 30 and 150 min and occurred before and/or after practices. The informal meetings aimed at helping coaches understand how to plan and implement Project SCORE strategies, envision novel approaches, and consider athletes' developmental needs in a meaningful manner.

During these meetings the coach developer aimed to instigate coach reflection rather than provide answers and recommendations. Indeed, the coach developer used prompts to promote meaningful discussions such as what were the main objectives this week?, how have the athletes responded to the strategies you applied?, what were the main difficulties you had?; and what can you improve in your intervention?. A group messaging tool was also created for coaches within each youth sport organization to facilitate the exchange of discussion, sharing ideas, and reflexive routines. It should be noted that coaches were not pressured to implement the strategies explored in Project SCORE, but instead encouraged to use this resource as a starting point to promote PYD.

2.3.4 The follow-up phase

After the Project SCORE implementation phase ended, the measures described in the pre-intervention stage were used. This phase occurred between May 2023 and June 2023 throughout a three-week period.

2.4 Data analysis

Firstly, an examination of data normality was conducted, revealing that the variables did not follow a normal distribution ($p > .05$). For this purpose, the Kolmogorov-Smirnov test was employed due to the sample size being greater than 50. Gender differences were not calculated in this analysis. In order to control for individual variability in different moments, a mixed linear model (MLM) for repeated measures was chosen. This approach is suitable for analyzing data when observations are not independent, which is often the case in sports science research involving repeated measures on the same subjects or clustered data such as teams (36). This MLM accommodates data that may not meet the normal distribution assumption and can handle complex data structures with fixed (e.g., moment and sport) and random (e.g., participant's ID) effects (37).

Accordingly, this model provides the significant differences between factors using the Bonferroni *post hoc* test. The Cohen's d effect size (ES) was provided as a quantitative measure of the magnitude of the difference or relationship, offering insights beyond mere statistical significance, and helping to understand the practical significance of the findings. It was interpreted via the following ranges: <0.20 = trivial effects, 0.20–0.49 = small effects; 0.50–0.70 = moderate effects, and >0.8 = large effects (38).

3 Results

Table 1 provides the results across the subscales of the athlete questionnaires and the results of the analyses investigating differences pre- and post- intervention.

3.1 Athletes′ perceptions

3.1.1 Connection

Differences between pre- and post- assessment were analyzed on the CART-Q. For the coach-athlete relationships, statistically significant increases were identified for commitment ($p < .001$) and complementarity ($p = .009$). The PYD-focused CEP demonstrated to have a moderate effect size from .01–.57 in some subscales, which highlights areas where the program was particularly effective.

3.1.2 Confidence

Regarding self-confidence, the results from the unstable self-confidence subscale showed a significant change with unstable

TABLE 1 Mean and standard deviations scores of pre and post intervention across the subscales of athlete questionnaires.

	M Pre (SD)	M Post (SD)	*p*	E.S.	*α*
Connection					
Commitment[b]	5.9 (.97)	6.5 (.74)	<.001	.57	.58–.67
Closeness[b]	6.8 (.50)	6.9 (.41)	.132	.18	.73–.86
Complementarity[b]	6.5 (.56)	6.8 (.52)	.009	.31	.65–.76
Confidence					
Robust[c]	5.6 (1.9)	5.5 (2.1)	.988	.01	.77–.79
Unstable[c]	5.6 (2.1)	4.2 (2.4)	<.001	.56	.83–.86
Competence					
Skills[b]	6.0 (.92)	6.4 (.68)	<.001	.51	.85–.83
Cognitive[b]	5.8 (.94)	6.3 (.64)	<.001	.60	.80–.73
Resilience[b]	5.5 (1.1)	5.9 (1.1)	.011	.36	.87–.91
Character					
Anti-Teammates[a]	1.6 (.60)	1.4 (.39)	<.001	.42	.77–.67
Anti-Opponents[a]	1.7 (.62)	1.6 (.39)	.154	.20	.82–.69
Pro-Teammates[a]	3.7 (.83)	3.9 (.73)	.020	.30	.66–.58
Pro-Opponents[a]	2.3 (.94)	2.6 (.83)	.025	.26	.58–.47

[a]1–5 Likert-scale.
[b]1–7 Likert-scale.
[c]1–9 Likert-scale.

confidence decreasing at follow-up ($p < .001$). The effect of CEP had a moderate size effect (ES = .56).

3.1.3 Competence

The three subscales of the competence measure showed statistically significant increases at follow-up. Specifically, skills, cognitive, and resilience subscales of the measure positively increased. In addition, effect sizes across subscales were .51 for skills, .60 for cognitive, and .36 for resilience which represent small to moderate effects of the Project SCORE CEP.

3.1.4 Character

For the character scale, statistically significant differences were found in the subscales of: Anti-Teammates (AT; $p < .001$), Pro-Teammates (PT; $p = .02$), and Pro-Opponents (PO; $p = .025$). In general, the effect of the CEP was small (.30–.42).

3.2 Coaches' perceptions

Coaching for life skills. Across the subscales of the measure, four showed increases following the workshop while one (sport climate) decreased (Table 2). The decrease in sport climate was significant at follow-up ($p = .042$) while practicing life skills ($p = .039$) and practicing life skills transfer ($p = .005$) increased significantly. On the other hand, discussing life skills and the discussing of life skills transfer did not change significantly. Regarding effect sizes of the CEP, values ranged between .24 and .98 indicating small to large effects over the study (see Table 2).

4 Discussion

The purpose of the present study was to assess the effectiveness of a Project SCORE intervention on coaches' and athletes' perceptions involved in competitive youth sport programs. In addition, this is one of the first studies to evaluate the impact of a CEP using Project SCORE as the base for knowledge (19, 23). Another unique aspect is the fact that studying youth from a Portuguese competitive sport system provided contextualized insights about if/how Project SCORE can impact the development of the 4Cs in athletes and coaching for life skills in coaches. Studying athletes within a competitive context was deemed necessary to grow our understanding of PYD within contexts that are often deemed as inconsistent with the PYD framework and holistic development [e.g., (39)].

TABLE 2 Pre and post scores of coach participants along with pre- and post- difference, effect sizes, and pre- and post- reliability analyses.

	M Pre (SD)	M Post (SD)	*p*	E.S.	α
Sport climate	5.7 (.36)	5.44 (.37)	.042	.63	.83–.85
Discussing ls	4.9 (.99)	5.05 (.74)	.602	.24	.91–.90
Practicing ls	3.7 (1.5)	4.67 (.99)	.039	.64	.95–.88
Discussing transfer ls	4.5 (1.1)	4.90 (.89)	.266	.32	.82–.93
Practicing transfer ls	3.0 (1.2)	4.25 (1.01)	.005	.98	.80–.70

ls, life skills.

Traditionally, there have been perceived conflicts between competitive contexts and psychosocial development that can lead to misconceptions about the development of psychosocial skills in competitive youth sport (40). Therefore, the present study provides an opportunity to reflect on how PYD and athletic performance can be positioned as interrelated and inseparable objectives. Indeed, past research has shown cases of tensions between competition, performance and PYD [e.g., (18)]. However, findings of the present study highlight how Project SCORE had a positive effect on both athletes' and coaches' perceptions within a performance context and provide opportunities for policy makers, sport organizations, coaches, and CEPs to consider personal development within competitive contexts.

In the present study, there were significant differences between pre- and post-measures concerning athletes' perceptions associated with the 4Cs. With regards to connections, particularly those between coaches and athletes, there were significant differences on the quality of the coach-athlete relationship for both to complementary and commitment. Past research has highlighted the importance of the coach-athlete relationship in achieving PYD outcomes such as life skills [e.g., (4, 41)] and mediating intentions to continue sport participation (42). Despite the lack of significant results concerning closeness, it is important to note that athlete scores were high (i.e., the maximum was seven points and the athletes scored 6.9 after the PYD-focused CEP).

Hence, to interpret these findings in a comprehensive manner there is the need to consider several factors. Athletes reported high perceptions towards the coach-athlete relationship at the pre-intervention phase which may help explain why (a) there were no significant differences on closeness and (b) a ceiling effect may have occurred at the follow-up phase. Considering the competitive nature of the Portuguese youth sport system (27), coaches may have increased their ability to create relationships through meaningful and long-lasting cooperation (i.e., complementary and commitment) to achieve better performance outcomes. In this sense, coaches may see value in a PYD mandate, particularly in improving the quality of coach-athlete relationships because these are a key component of the coaching process and may help achieve performance outcomes. Additionally, PYD can be a part of a set of demands imposed by sport organizations, which occurred in the present study. It should be noted that coach and athlete participants were recruited from two sport organizations who were willing to consider PYD and partake in this intervention. In other words, sport administrators were the ones deciding whether Project SCORE would be implemented, but coaches also played a complementary role in this decision-making process. Subsequently, coaches may have valued the presence of a coach developer because they wanted to optimize professional development processes, become more effective, as well as fulfill organizational demands.

Previous studies grounded on partnerships and collaborative efforts between researchers and practitioners have demonstrated positive outcomes (10), indicating that such cooperations are crucial. This may suggest the need to carefully consider how to establish meaningful partnerships with sport organizations and develop contextualized strategies [e.g., (10, 43)]. For instance, in some cases PYD as an organizational objective may need to be mandated by sport administrators and policy makers that hold social capital over coaches and other actors. Such mandates could continue to reinforce the notion that PYD and performance can indeed be complementary rather than incongruent when considering holistic youth development. As research on PYD continues to develop and expand to multiple countries across the globe (44), Portugal may reflect an example of how PYD and performance are starting to become interrelated components of youth development [e.g., (28)].

Findings showed significant differences between pre- and post-measures. Specifically, there were significant decreases in unstable self-confidence, despite no significant increases in robust self-confidence. Concerning competence, there were significant changes in skill, cognitive development, and resilience. Lastly, with regards to character there were decreases in antisocial behaviours with teammates and increases in prosocial behaviours with teammates and opponents. Taken together, these findings support previous studies of PYD-focused CEPs which have positively impacted athletes' perceptions of the 4Cs (20, 21). One important consideration is that the Project SCORE workshop was embedded by coaches as part of a competitive context and once again demonstrates that these contexts are not incongruent with the promotion of PYD. These findings further demystify the common conceptualizations that competitive environments are independent from PYD mandates (40).

Our findings of positive impacts of a PYD-focused CEP with youth sport participants engaged in highly competitive environments adds to our understanding of personal development within youth sport. Previous studies have reported more limited impacts of PYD-focused CEPs on athletes' perceptions [e.g., (26, 45)]. For instance, Junior et al. (45) highlighted how competitiveness may influence coaches' perception of PYD and effectively connect this approach to performance objectives. The findings of the current study support Junior's et al. (45) recommendation that coaches and parents should not only create an environment that develops life skills but also discourage antisocial behaviors towards opponents. Nonetheless, competitive environments may have athletes disregard behaviours towards opponents and/or neglect the need to change certain behaviours in competitions.

To further understand the interrelatedness of competitive sport and positive development it is important to delve deeper into the context. At different times over the course of a competitive season, PYD and performance will vary in importance. For example, athletes and coaches may value PYD more readily during less competitive parts of a season or during practice while focusing on performance during specific competitions or tournaments. This suggests a non-linear process where PYD and performance are continuously valued at different moments. These fluctuations can lead to both implicit and explicit approaches to PYD (4) if the participants and coaches agree that PYD is a valuable goal in youth sport, but it is addressed more at certain times and in specific contexts.

As mentioned above, coach participants in the current study were conveniently selected and were interested in pursuing PYD within their context. The positive outcomes in the promotion of PYD post-workshop corroborates previous studies (43, 46). Despite the positive outcomes, coaches decreased in the perceived ability to promote a positive sport climate and discussing life skills and life skills transfer. These findings may showcase context-specific variables associated with this socio-cultural context that resonate across cultures. First, Bean et al. (7) highlighted how implicit-explicit strategies related to coaching life skills should be positioned as interrelated. In other words, coaches may use a variety of implicit-explicit strategies at the same time and value diverse types of strategies differently across time. One should have in mind that explicit strategies may be positioned as critical for performance development [see (39)]. Second, the fact there were no significant changes on coaches' perceived ability to discuss life skills and life skills transfer may be explained by the cultural relevance of PYD in coaches' discourses. In other words, PYD and life skills are North American concepts (47) and may not be part of coaches' discourses, language and interactions. These concepts may be transformed into more culturally appropriate and common words and expressions such as "values", "attitudes" and "personal development" can enhance understanding and acceptance among coaches, enabling them to integrate these ideas more effectively into their practices and interactions with athletes. Third, coaches may have been concerned about athletes' responses to these new concepts in such a performance-oriented environment and losing credibility. Explicit discussions around PYD may not be seen as automatically useful and/or needed. These results may also have derived from the fact that a learner-centered approach was used, which enabled the coach developer to tailor Project SCORE per coach participants' learning needs, as well as leverage PYD with performance objectives. Finally, the design of the intervention, especially the sustained engagement between the coach developer and the coaches over a 21-week period played a crucial role in effectively infusing implicit and explicit strategies into coaching practice. This prolonged interaction allowed the coach developer to tailor contents, strategies and approaches to the unique contexts of each coach, thereby enhancing the overall impact of the intervention. It was important to ensure the PYD-focused CEP was aligned with the demands of competitive youth sport programs.

In the present study, there are some limitations and future directions that need to be considered moving forward. First, the study involved a small sample of coaches and athletes, which creates challenges in extrapolating the findings to similar settings. Second, due to wide age range used for the athlete's sample (e.g., 10–17 years old), combined with the small sample, was not possible to evaluate the differences regarding the age of the athletes. Third, some of the Cronbach's Alpha values were below usually acceptable criteria due to the sample size. Finally, the athlete sample was composed of mostly female athletes, which may also limit generalizability. Moreover, sample characteristics did not enable an examination of differences between genders amongst coaches and athletes. Together, these limitations encourage us to interpret the findings with caution but also open up avenues for further research to better understand how additional variables influence coaching practice.

Based on these limitations, future studies could attempt to refine our understanding of PYD within competitive contexts.

There is the need to assess interrelationships between competitive climates and personal development. In most cases, PYD has been assessed and investigated detached from other coaching concerns, objectives and practices (e.g., physical development, tactical development). Essentially, if the purpose is for coaches to coach holistically and satisfy competitive demands, future research designs may need to follow the same approach. On this notion, with regards to the evaluation of the effectiveness of PYD-focused CEPs such as Project SCORE efforts may need to be deployed towards understanding coach and athlete perceptions and behaviours in competitions, moving beyond simply analyzing practices. Also, it is important to address potential differences in coach-athlete relationships based on gender and age as these could influence the dynamics and outcomes of coaching practice. There is the need to explore how the relationship between coaches and athletes varies according to age and gender. Finally, to appropriately map change across youth sport systems, future research endeavours may also need to investigate the evolution between personal and performance development within competitive youth sport programs.

5 Conclusions

Within Portuguese youth sport, there has historically been an emphasis on competition (27). Despite past research in the context not demonstrating overly positive effects of a PYD-focused CEP (18), the current study found positive effects with competitive coaches and athletes. The exact mechanisms for these results are unknown and would warrant further research. However, given that researchers in Portugal have been promoting PYD for the better part of the last decade (18, 48), it is possible that the current findings represent small changes in openness and behaviour toward PYD. Once again, further research needs to evaluate this claim but ultimately, the findings hint towards possible integration of PYD within performance-based contexts. As such, coaches, coach developers, sport administrators, and policy makers can use the present findings in evaluating their programs and adjusting them to provide space for PYD to live alongside performance.

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 Polytechnic Institute of Santarém, number 072021. 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

MF: Writing – original draft, Writing – review & editing. FS: Writing – original draft, Writing – review & editing. MF-V: Writing – original draft, Writing – review & editing. JM: Writing – original draft, Writing – review & editing. LS: Writing – original draft, Writing – review & editing. DM: 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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Mental processes in professional football players

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Objective: Clear connections have been found between mental processes and performance in elite level football. Yet, few studies have investigated how professional football players' experience the influence of mental processes on performance.

Method: This study used a qualitative research design and in-depth interview of six Norwegian professional football players at elite level with a mean age of 28, 3 years and represented five professional clubs. The aim of the study was to investigate how they perceived the importance of arousal regulation, mental toughness, and self-confidence, and that of the sport psychologist in developing these skills.

Results: The results revealed a complex and multifaceted link between mental processes and performance. All players, demonstrate a conscious awareness of how mental processes influence their performance. The use of a sport psychologist in working with mental processes emerges as a crucial factor for developing their mental skills. Another important aspect is the need for increased knowledge about mental training's effect in elite football. Mental toughness emerges as the most significant mental process for players' performance because it makes them capable of coping with challenging situations and periods.

Conclusion: This study shows that mental processes are important for performing, both related to arousal regulation, and self-confidence, and especially mental toughness. However, mental toughness was also considered a product of age and experience, where older players tend to have experience of more situations that enable them to handle adversity better than younger players. Interestingly, the youngest players seem to be most aware of the use of a sports psychologist.

KEYWORDS

mental processes, mental toughness, arousal regulation, self-confidence, professional footballer, sports psychologist

1 Introduction

Professional sports require the performing athletes to possess a range of skills. One of the most challenging set of skills to develop are the mental skills to cope and develop as an elite athlete (Konter et al., 2019). Compared to non-elite athletes have elite athletes been found to have higher score in self-efficacy, emotionality, present fatalistic time perspective, past positive time perspective, and openness to experience (Mitic et al., 2021). A vital part of developing mental skills is the mental processes which refer to internal, invisible, activities in our minds. These include thinking, reasoning, and problem-solving, and form the basis of our actions, decisions, and feelings (both conscious and unconscious), which govern the person's perception of themself and their surroundings, and processes that form the basis of their emotions and desires (think, understand, learn, remember, and make decisions) (Ivarsson et al., 2020). Research has shown that mental processes (and the mental skills learned in the process) are important contributors which not only directly influence their ability to perform at their best (Nesti, 2010), but also indirectly by optimising other skills required to succeed at the top level (Williams et al., 2020).

Sports psychology research has a wide range of both qualitative (Gould et al., 2002) and quantitative (Mitchell et al., 2014) studies on elite sports. However, there is a narrower selection of both qualitative and quantitative studies on professional football players' experiences (Ivarsson et al., 2020; Jordet, 2019), despite several quantitative studies at the junior level (Benítez-Sillero et al., 2021; Forsman et al., 2016; Saward et al., 2020), showing that older junior players can withstand tougher mental stress. The conscious and active use and development of mental processes is necessary to better handle poor performances (Saward et al., 2020). Furthermore, footballers who have become professionals had clearly prominent psychological skills at a young age, such as increased self-confidence, commitment, and ability to handle pressure (MacNamara et al., 2010; MacNamara and Collins, 2011; Rye et al., 2022).

Three mental skills which have been shown to be important and partly connected to performing well in professional football are mental toughness, arousal regulation, and self-confidence (Williams et al., 2020). Mental toughness is the most complex phenomenon, and is related to endurance, continuity, and motivation (Jones et al., 2002). It is the ability to handle poor performance and stressful situations such that it does not negatively affect performance. According to DeWiggins et al. (2010) mental toughness can be described as the ability to be focused, composed, and safe in stressful situations. Some characteristic features of people with high mental toughness are their ability to assess and reflect on their own performance, high self-esteem (self-confidence), and a good ability to handle adversity (Wieser and Thiel, 2014). The literature reveals clear connections between mental toughness and performance, and the importance of this mental process as a psychological aspect (Thelwell et al., 2005; Coulter and Thelwell, 2019). Thelwell et al. (2005) found that soccer players suggested that players who demonstrate attributes resembling a high level of self-belief and an ability to cope with the internal and external pressure that elite sport places on the performer, tend to be perceived as mentally tough. Furthermore, Miçoogullari and Ekmekçi (2017) found a positive correlations between psychological skills training and mental toughness among professional football players, in a sixteen weeks training program. Statistically significant differences were found between pre-test and post-test values which were been confidence, constancy, control, mental toughness, self-acceptance, positive relations with others, autonomy, and psychological well-being.

The sports psychologist is an important actor for developing psychological skills in professional football (Nesti, 2010). However, they face four main challenges in delivering in elite and professional sports: congruence (operating authentically, and in line with their personal philosophy and with their chosen methods), having a broader role (e.g., managing multiple relationships), influence of elite sport cultures, and surviving and thriving (McDougall et al., 2015). Similar challenges have been found in football (Kremer and Marchant, 2002; Jordet, 2019; Feddersen et al., 2023).

If the athletes are doing an individual or team sport, they are a part of a team of performers and influence each other's development and performance. The individual footballer must also function as part of a performing team. Langagergaard (2017) pointed in this regard on the importance of establishing conditions for a common language that forms the basis for a group to develop a performance culture together. The concept is a cyclic, temporal, and transitional approach, and serves as common language of reference regarding performance psychology (described further in Langagergaard, 2017). The "four phases" consists of: "pre-phase" (phase 1), "during-phase" (phase 2), "post-phase" (phase 3) and "transfer-phase" (phase 4). The first the "pre-phase" (phase 1), which is a preparation phase for the individual (and/or team preparation) at the practical, physical, and psychological levels; essentially, this phase is "getting ready to perform". In football, phase 1 can be understood as match day preparation, locker room time, and warm up. Phase 2, "during-phase", refers to the duration of time where an actual performance is taking place; in football, it can be translated into the first or second half of the actual football match. Phase 3 is the "post-phase" and is characterised by evaluation. It involves processing impressions and to some degree being able to "learn & close" the performance over time and then moving onto to phase 4. Phase 4 is the "transfer-phase", characterised by resetting, recover and "switching off" from the performance mode. This four-phase approach takes the perspective of the individual (player) and the use (aware/not aware) of well-known mental training techniques within three domains: intend, attention, and intensity, i.e., motivation, goalsetting, arousal regulation, focusing, mental routines (pre/during/post), and mindfulness.

Here, our intention is to dive into professional footballers' experiences of the influence of mental processes on performance in a Norwegian context which lacks research and how they have developed these processes with the help from a sport psychologist. We therefor interviewed six Norwegian professional football players to seek to gain insights into professional footballers' experiences of and around the relationship between mental processes and performance, especially those related to mental characteristics such as arousal regulation, mental toughness, and self-confidence. Furthermore, we explore the players' perception and experience of what Langagergaard (2017) has described as a common language related to mental skills and processes while working with a sports psychologist in both their current and earlier clubs.

2 Methods

The study investigates how professional football players perceived the importance of the mental processes and use of a sport psychologist, and how these influence their performance as players. The study focuses on the everyday interactions between individuals. Further, the meanings with these interactions are managed and transformed through peoples' interpretative processes. Hence, we have taken a social interactionist ontology stand and utilise an interpretivist approach (Markula and Silk, 2011; Wahyuni, 2012). The study was approved by the Norwegian Centre for Research Data (reference number 410262) prior to the data collection.

2.1 Participants

All interviewed players were professional football players at the elite level (one player played level 2), had a mean age of 28,3 years (SD = 4.3), and represented five professional clubs. These players had a long experience in professional football and were recruited by the first (3 players) and last authors (3 players). Both these researchers have a network of acquaintances as they were a part of a professional football academy and a researcher of professional clubs for a decade, respectively.

2.2 Interviews

The interviews took place either at the players clubs or digitally, and lasted between 23 and 50 min, with an average of 39 min. Three interviews were conducted face to face, while three was done digitally (Zoom). Each participant was interviewed only once and by the same interviewer. All interviews at the clubs were conducted in a quiet area which was chosen by the participants, with only the interviewer and participant present. The interviews used a semi-structured approach, as detailed by Brinkmann and Kvale (2018), and were audio recorded and later transcribed verbatim (see Appendix 1 for the interview guide). To ensure confidentiality, all participants were anonymised in the transcriptions and their pseudonyms were used (see Table 1).

Adopting a social interactionist ontology and interpretivist epistemology enabled us to frame our interviews as a relational space, meaning that both the participants and interviewer could explore themes together and co-construct knowledge (Markula and Silk, 2011; Wahyuni, 2012). The interview guide used to structure the interview process included the following topics: *arousal regulation, mental toughness,* and *self-confidence* (see Appendix 1 for the complete interview guide).

2.3 Data analysis

We examined all interview materials using a six-step thematic content analysis developed by Braun and Clarke (2006) and Braun et al. (2019). First, the first author transcribed, read, and re-read the data. Second, the same author generated initial thematic codes by inductively analysing the data (for example, 'mental match preparations'). Third, these were then presented to the second and third authors, whose role was to act as 'critical friends' who reviewed and challenged the first author's descriptions and reasonings for these initial codes. All authors discussed how the findings should be categorised and structured into higher-order themes (for example, 'Understanding and use of mental processes'). Fourth, all authors then jointly elaborated on the analytical themes and returned to the raw interview data to clarify questions (for example, what relationship did the players have while working with a sport psychologist). Fifth, the sub-themes and final categories were reviewed and refined. The final step combined the analytical and categorisation processes. Hence, the authors often went back to the categories and raw data to ensure that the content was fairly and accurately based on what had been defined during the report writing process.

3 Results

The results are centred into the following topics: understanding and use of mental processes, mental toughness, arousal regulation, self-confidence, and the role and use of a sport psychologist with respect to performance.

3.1 Understanding and use of mental processes

The fluid concept of mental processes described in the research literature was also reflected in the players' answers, which ranged from general thoughts on the use of, for example, inner dialogue to more specific thoughts related to toughness, as described by Frank below:

TABLE 1 Description of the participants.

Player ID	Age group	Experience with a sport psychologist	Playing level	Other information
Tommy	20–24	Access to SP in club, no personal relationship with SP	Norwegian elite level (experience from different elite level clubs)	Age-specific national team matches, no education.
Chris	30–34	No access to SP in his club (external lectures), no personal relationship with SP (lack of time with SP)	Norwegian elite level 2 (experience from different elite level clubs)	Been in same club during his professional career. Same club as P4. Two non-sport related bachelor's degrees
Oscar	30–34	Access to SP in shorter periods, personal relationship with SP	Norwegian elite level 2 (experience from different elite level clubs)	Sport related master's degree
Peter	20–24	No access to SP in his club (has reach out to a SP), had personal relationship with SP	Norwegian elite level 2 (experience from different elite level clubs)	Age-specific national team matches, same club as P2, non-sport related education
Frank	25–29	Access to SP, personal relationship with SP	Norwegian elite level (experience from different elite level clubs)	Non-sport related bachelor's degree
Oliver	30–34	Access to SP, personal relationship with SP	Norwegian elite level (experience from different elite level clubs)	Age-specific national team matches, team captain, non-sport related bachelor degree, current student

> Frank: Mental processes is for me, it really means how much you can stand to actually endure. It could be if you get injured, then you have to deal with it and come back from it. How do you deal with it if you have a bad game or a good game, are you able to basically reset from both of those for the next practice and the next game[,] or are you affected by that?

Still, the players valued the importance of focusing on these mental processes continuously and dynamically. This is in line with earlier research on a performance culture with changing situations and difficult periods (MacNamara et al., 2010; Thelwell et al., 2005), where the players are expected to perform and handle pressure (Dodd and Newans, 2018; Williams et al., 2020).

> Frank: Actually, the most important thing is to try to have a continuous process. It cannot be the case that you screw it up, and then suddenly an important match comes up and you have to focus a lot on that. Then I think it goes against its purpose.

However, some players described the process of going through the different challenging thoughts, thought by thought so to say, to be able to address them instead of ending in, as what one of the players describes, a black hole:

> Tommy: Often it is also like this if there are periods when things are a bit tiring, such as if you are injured, you see someone else doing well, you see that you might not make the team straight away, then there are many small things advice. Then you have to go in order and process each and every thought and get done with them, instead of it becoming a black hole with a lot of negativities.

The clearest finding was the players use of their experience and career, since it has made them more conscious of their own mental processes and how it has impacted their performance. Similarly, research has indicated that older players can better handle a mentally tough load, and that a conscious relationship to these processes also indicate a bigger likelihood of handling weak performance (Saward et al., 2020). Tommy states:

> Tommy: It is something that has come in recent years for me. I have simply become more observant of it. In recent years, I have been trying to think about it. Because when I was younger it was just like 'yeah, then I got it, screw it and do not think about it', but then it got to me a bit more than I thought. So now, if I've been taken out of the team for a game, I have to process the thought of why, and this and that, and finish that thought and then move on, instead of carrying it on to match day and all of next week.

3.2 Mental toughness

All players unanimously mentioned the importance of mental toughness and considered it to have the most direct impact on their performance, especially during games:

> Chris: The most important thing for me is when I'm playing and in the heat of the game, to be strong mentally. You see, for example, Haaland, he is perhaps the world's toughness player when it comes to adjusting on the pitch, and constantly chasing the next. If he misses a chance, he knows that another one will come very soon.

The players describe mental toughness as partly being rational in how they should face the challenge and focus on the things they can impact, and looking ahead in time on the challenges to come.

> Frank: In a way, I have a kind of attitude that if you dare to stand in it and believe in what you are doing, then you will get what you deserve in the end. Then usually comes the reward too, so for me it has been an important thing to just stick with it and not be too impatient.

The players mainly talk about mental toughness as the ability to handle adversity by being patient and believing in themselves. As prior research indicates, they still relate mental toughness to self-confidence (Machida et al., 2017; Vealey and Chase, 2008). Tommy describes using inner dialogue as a tool to gain self-confidence to allow them to be mentally tough and highlights the relationship between mental processes (Liew et al., 2019; Williams et al., 2020).

> Tommy: I know what I can do and I'm better than my opponent if I meet someone in position on the court. I do not know if I'm fooling myself or if I'm actually better, but in my head, I am, I honestly believe I'm better than him.

To be able to perform, the players talked about their individual performance and how they were tested mentally in periods. A player, Oscar, stated, 'It is perhaps particularly important to have these types of things during the periods when you are being tested a bit, if you are a bit in and out (of the team), or if you encounter a lot of adversity'. They also highlight the importance of social–emotional support via teammates and their mentality when the team faced challenges as a team.

> Oliver: In a way, people in slightly bad times just distance themselves from the project and the team and want to have less to do with it compared to when things are going well, because then everyone wants to be part of it. So being in emotional balance and creating energy and trying to support those around you in bad times, that's also an important phase then.

As highlighted was age, experience, and family situation understood to impact their mental toughness. One of the players, Chriss, described how a bad involvement in a game affected the next game at an earlier age, while they had now become better at readjusting according to the situation.

> Chris: In the past if I made a mistake or lost a duel or lost a match or something, it could affect me for a long time then, and maybe become a little destructive. Now I think that I am much better at adjusting and thinking about the next situation, the next training session, the next match, and I think that will perhaps come a little with experience and age.

Players noted how they learn through experience by reflecting on their own performances (DeWiggins et al., 2010). For instance, when they were younger, they could see what was needed but still considered it hard to do this right thing. Others also highlighted that they gained a new perspective when they became a parent, as they had to change focus and let go of some thoughts when they got back to their family after the game or training. For instance, Chris stated, 'I now have a child that I come home to, which means that when I come in the door now, I have to readjust and think about other things'.

3.3 Arousal regulation

Players highlighted a need for arousal regulation before the match. They arousal regulation as a part of their mental process and it impacts them in a positive way if used wisely, since too much energy might have a negative impact:

> Frank: Before then I was very much like looking forward to the match and you kind of walk around waiting for the match to start, and that was actually one of the first things I brought up with the mental coach.

When talking about their thoughts during games, players highlighted the need to be focused and not let the mind wonder away, and stay in the present. Oscar noted, 'If you walk around thinking about too many other things, then you have not found the right tension level'. Meanwhile, others talked about situations where they needed to adjust their arousal either up or down.

> Oliver: Coming to the stadium in the city, it was like 'here I have to work on myself', compared to playing an eight o'clock match in the stadium in front of a number of spectators with floodlights, I actually feel that. And the feeling you get is that 'here you get free energy and excitement'.

As a part of their arousal regulation, some players, such as Chris, used self-talk as an unconscious and automated mechanism to not open the mind to impressions in pointed and important moments (Beilock and Gray, 2007). Self-talk is used, for example, to avoid a high degree of tension from actors in the external environment. Here, an automated process is clearly initiated in which one thinks step by step; that is, it is an unconscious awareness of how one solves difficult situations by making the necessary adjustments required by the situation (Beilock and Gray, 2007).

Still, we also found individual variations during matches, where some players are conscious of their use of self-talk as a tension-regulating technique:

> Oscar: The way I work, I work a lot with the way I talk to myself and about myself. And there is a lot to do with self-confidence, if you are able to describe yourself well, and tell yourself that you are good, then you will also perform better.

3.4 Self-confidence

Self-confidence was considered to impact performance (Knight et al., 2017), especially in decisive situations during a match (Machida et al., 2017):

> Peter: After all, you get tremendous self-confidence from good performances. It's actually what gives me the most confidence. The more good things you do, the better you play.

Furthermore, players perceive a relationship between self-confidence and performance, as highlighted by research (Hwang et al., 2017). Often, older and more experienced players are expected to be self-confident. Still, players consider self-confidence to also be important early in the career:

> Oliver: Confidence is something that is… it's not something that's permanent, it's fleeting. And that is independent of whether you are 15 or 30 years old. I've felt a lot of that kind of security in the last 10 seasons, and then I kind of get it NOW, when I'm old (30–35) and feel like I'm like 'damn, I'm 15 years old and insecure and that bit'. In a way it's kind of nice to feel that. It is perhaps as much about the fact that self-confidence is something that is not permanent then, that you have become more experienced and older, because self-confidence is a fresh commodity.

Thus, self-esteem is highlighted as a phenomenon that can occur regardless of age and experience (Knight et al., 2017). Peter points to this, stating "In the past I could think, 'Shit, I cannot do that, because I'm not very good at it,' and then you usually fail when you have that mindset". As the players also highlight, self-confidence can come from other parts of their lives (i.e., education). Oliver believes that it is also important to master other arenas to avoid that everyday life as a footballer becoming all-consuming and highlighting the value of studying, 'In the current period, education gives me a lot, that you have another arena to feel mastery in'. He also highlighted how the lack of mastery during injury periods negatively affected his self-confidence, 'The reason why I have little self-confidence after periods of injury, for example, I know it's about the fact that I have not had recent experiences where I've somehow mastered situations that have given me self-confidence'. Others experienced the opposite when they got injured as no longer have the pressure to perform, which positively affects their self-confidence:

> Peter: What's a bit funny actually, is that when I'm injured, that's perhaps when I gain the most confidence. Then you get a bit out of the football bubble, you kind of do not have to perform every day, and then you kind of get to reset a bit.

In this professional football context, the fear of failure could overcome the joy of success (Coulter et al., 2010). Then, self-talk and inner dialogue can be used as a preventive tool by using affirmations that create security and self-confidence, as Peter tells (Konter et al., 2019). Such affirmations are exemplified, as S1 notes, as a tool to overcome negative thinking; or, as Frank highlights, relate self-confidence to self-image, which can be the basis for a solid self-confidence.

> Tommy: If you first start to doubt, then it's about being able to reset a bit, and put your finger in the ground and think 'where am I?'. Yes, I play at a club and I'm here for a reason. There's a reason why I'm here, I'm a good football player somehow.

Frank reflects on how both well-being and one's qualities impact self-confidence, and thus, performance. They describe the inherent feeling of feeling good off the pitch as an important premise for performing on the pitch. Peter also refers to this inherent self-confidence as a strong desire, '[I do not] want good performances on the field to give me good self-confidence. I'd rather have an automatic self-confidence elsewhere in life that also makes me confident on the pitch'. However, although self-esteem is shown to be a dynamic phenomenon, self-image emerges as the most fundamental source of continuous self-esteem.

Another way of impacting the players' self-confidence is the use of videos and visualisation, which many players describe as useful to boost their self-confidence. Oscar notes, 'Maybe watch a video of things I've done, so for me it works then, in periods where I feel like I'm not mastering everything (Tommy) and: I like to watch videos of myself succeeding'. In a professional football context, mental skills can divide the professional players from the non-professional ones (Coulter et al., 2010). This also highlights the multidimensional aspect, since mental processes not only impact performance, but that also other mental processes.

3.5 Players' use of a sport psychologist and their impact on performance

Players described a wish to have access to a sport psychologist in their own club, consistent with research on players in English professional football (Nesti, 2010). However, players' actual access to a sport psychologist differed (see Table 1):

> Chris: We do not have anyone who is a permanent employee, but I could definitely imagine it. I think maybe in football you think that in a physical team or medical team, you have to have a club doctor and a physio, and maybe a physical coach, but I do not think you often think about how important it could be to have a mental coach as well.

As Chris stated, the sport psychologist introduced new specific techniques unknown to them before. Peter stated, 'It is the mental coach who have given me such techniques', which they describe further as follows:

> Peter: Out on the pitch, I have learned from the mental coach that I should occasionally take a few breaks where I reset and breathe in, breathe out, in and out, in and out a few times to calm myself down on the pitch, and reset and be ready again.

Trust was an important issue for some players. Research shows that mental techniques, such as visualisation and meditation, are effective (Konter et al., 2019), which was highlighted by one player. Others specified how they have used meditation, mindfulness, arousal regulation, and inner dialogue to overcome difficulties.

> Oscar: I have become better at being aware of the way you talk to yourself, how it can affect performance, and just letting go and you do not always have to perform at your best.

Still, some players had not been able to use these learned techniques, although they know they have been found to be effective:

> Oliver: If there had been some specific techniques that had worked for performance development, then it would have been much easier. I feel that it gets a little too diffuse and a little too high hanging sometimes, things like visualisation and meditation and that bit. I know in a way that research says that it can be beneficial, but I have not been able to translate this knowledge into 'oh, this I know works' and this gives me better conditions to perform, I have not found that yet.

Others did not use the sport psychologist the team had access to. Instead, Tommy used their experience, stating, 'I have good control over it on my own and have found a method that works well for me, and then I continue with it until I feel that it does not work anymore'. The player focused on former experiences and that this affected his performance in professional today.

Although the players had difference experiences with a sports psychologist, all players had experience with one or more during their career. For some players, the sports psychologist's impact was related to periods with many matches and the frequent need to perform, or during injury periods. Meanwhile, others highlighted their general value and how other clubs had success with using one.

> Chris: You see, for example, that they have done it in a rival club, and there they have paid tribute to the work of a sports psychologist. It is about percentages, and of course at the top level you are more dependent on margins. If you can get margins from having a mental coach then it's worth it, but of course it also depends a lot on club finances and priorities and things like that.

Thus, the impact of the sports psychologists appears to be different from an individual or group perspective. Most players highlight the individual talks with the sport psychologist, while there was one exception, Tommy, who liked the team talks better than the individual talks.

> Tommy: I think the presentations he had in front of the team were very nice. I liked them a lot, because then he generally talked about tricks and such, to get into battle mode as a team. It seemed to the group that they also thought it was good, but as a duo I struggled a bit, I did.

The players with experience from international football highlighted both the individual and team talks. They noted how the mental coach had helped them and the team to redirect the focus and handle especially the media attention. Furthermore, the mental coach also equipped them to cope with the increased tension when competing on a higher performance level.

> Frank: We have been out in Europe a bit, where things are quite different from Norway, and where there is even more media and even more pressure on you from the outside as well. He the mental coach has been great there, he has come in and in a way talked about how we as a group and individuals can shut out disturbances.

Some players did reflect on why they did not have access to sports psychologist. Peter noted, 'It's the economy and all that, we cannot afford it. The money is rather spent on an extra player. I believe deep down that coach thinks he is a good sports psychologist even then'.

Similarly, Chris, who belongs to the same club as Peter, said that they have received the same answers regarding the employment of a sports psychologist. Nesti (2010) highlighted the difficulties of convincing coaches and the club management to prioritise this when the economic aspect is often the issue. Oliver highlighted that this was out of their control:

> Oliver: I think it is the knowledge that is lacking a lot, and then I think that those in the club management today also have their own preferences. They are part of a football that was played years ago. So, the mental part was not even relevant (for them). When I talk about macho culture in our time, the culture they were a part of was really a proper macho culture.

Some highlighted the importance of the introduction of a sport psychologist at an early age. Peter stated, 'I think if I had not gone to a mental coach when I was 20 and learned a little bit more about it, I think I'd have hit the wall, I'm pretty sure'. These results show that the players used both concrete mental techniques learned by a sport psychologist and more general techniques during their careers which they have learned to use themselves. This is in line with earlier research stating that sport psychological interventions are effective on players' ability to handle stress (Miçoogullari and Ekmekçi, 2017; Nesti, 2010).

4 Discussion

We explored professional footballers' perceptions and experiences around the relationship between mental processes and performance, especially those related to mental characteristics such as arousal regulation, mental toughness, and self-confidence. Furthermore, we explored players' perception and experience of a common language related to mental skills and processes while working with a sports psychologist both in their current and earlier clubs.

The findings show that the youngest players seem to be most aware of the use of a sports psychologist. This may be because these players reach senior level earlier, which requires more of them mentally (i.e., mental toughness) than older players (Saward et al., 2020; Williams et al., 2020). Mental processes have been shown to be important for performing well (Saward et al., 2020), especially with respect to arousal regulation, mental toughness, and self-confidence. Players highlighted mental toughness as the most important mental process for their performance. This is because it is perceived as a fundamental mental quality for handling challenging situations before, during, and after matches (Thelwell et al., 2005; Wieser and Thiel, 2014). However, mental toughness was also considered a product of age and experience. Older players tend to have experienced more situations that enable them to handle adversity better than younger players. We also illustrated how self-confidence directly impacts on-field performance. This is consistent with the literature, which shows that compared with players with low self-esteem, a soccer player with high self-confidence will have greater faith in their own skills, and thus, will be more willing to take chances and challenges on the pitch (Coulter et al., 2010). Although the professional football context is an arena characterised by high performance, some players and clubs experience higher expectations than others. In this study, some players play in clubs which participate in major European tournaments, such as the Europa league, with higher external pressure and attention from the media. In such situation, using active mental training can increase mental toughness, and thus, players' performances (Miçoogullari and Ekmekçi, 2017).

The players' reflections revealed a desire and a need to work in a more structured way on the development of their mental skills in consultation with sports psychologists both as individual players and as a group of players (Nesti, 2010). Since the players related age and experience as two of the most decisive factors for the players' mental toughness, the lack of references (age or experience) reinforces the need for a sports psychologist to be able to handle the situation such that they contribute to increasing the player's and team's performance. Still, a foundation of trust is needed between the player and sports psychologist (Konter et al., 2019), especially in the professional football context because of the performance culture and need for short term results. Consequently, sports psychologists need to deliver visible results. This is part of the reason why several coaches and clubs are sceptical about employing sports psychologists because it is difficult to collect objective data (McDougall et al., 2015; Feddersen et al., 2023). No experience or perception will be interpreted the same by two players because of individual differences arising not only from genetics and the environment but also from their thinking (Nesti, 2010).

Langagergaard (2017) argued that the context of performance differs compared to other contexts, and may be similar to the context of the military or police. Furthermore, the author highlighted the need for establishing a common language to develop a good performance culture that the team can use to move in the same direction. In collaboration with a sports psychologist, if the club can create an interaction between this individual complexity and the incorporation of a common language in the player group, one may argue that the effect will be greater and the performances will improve (Langagergaard, 2017). Although an individual player has developed good techniques for themself or in consultation with a sports psychologist, one's own mental processes can prevent the full potential of the group of players, for example, by allowing their confidence to influence the outcome of situations in a match in a way that is disadvantageous to the player. Nevertheless, one can argue that there are reasons why one-to-one conversations are so important because it takes time to establish relationships that influence mental training (Nesti, 2010).

4.1 Strengths and limitations

This study does not distinguish between the players perceptions of mental coaches and sport psychologists, which is a limitation. Furthermore, mental coaches, who often have experience from the sports context, substantially differ from sports psychologists, who have an academic background from the field of psychology. Another limitation was that two of the authors knew the participants which also was part of the reason as why the players was recruited to the study. This might mean that they were biased to have a positive attitude towards both participating, but also to the topic of interest in the study. Such a strategic sample might mean that other players might have other experiences compared to this sample.

4.2 Future research

Future studies should include the actors related to players in the performance context of professional football, since their impact on players' performance is essential. Furthermore, case studies or similar approaches with follow-up or longitudinal studies can be conducted with the same players as they get older, and more experienced both as football players and with the field of sport psychology.

In the professional football context, players have many actors and stakeholder around them. Players often find it difficult to know which of these stakeholders are introducing stability and conformity in their everyday life. These actors/stakeholders are trying to impact them, and both directly and indirectly impact their performance. Future studies should through both qualitative and quantitative studies focus on how the players differ in their needs and how the surrounding set-up impacts their performance, as their performance is matches and training are related. Another area worth exploring is the degree to which their well-being is related to their ability to perform. Most studies have focused on junior football, whose context differs from that of performance and elite football. As such, more studies are needed in the latter context.

5 Conclusion

This study shows that mental processes are important for performing (Saward et al., 2020), especially those related to arousal regulation, mental toughness, and self-confidence. Players highlighted mental toughness as the most important mental process for their performance because it is perceived as a fundamental mental quality for handling challenging situations before, during, and after matches (Thelwell et al., 2005; Wieser and Thiel, 2014). However, mental toughness was also considered a product of age and experience. Older players tend to have experience of more situations that enable them to handle adversity better than younger players. Interestingly, the youngest players seem to be most aware of the use of a sports psychologist. This may be because these players reached the senior level earlier, which requires more of them mentally (i.e., mental toughness) than older players (Saward et al., 2020; Williams et al., 2020). This study indicates that coaches should focus on developing the players mental toughness and especially among the younger players in professional football since this study show that older players handle adversity better based on experience. Still, since the younger players had a more aware use of a sport psychologist, it might be that today's younger players has learned these skills to be able to keep up a career in professional football.

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 Norwegian Centre for Research Data. 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

JG: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. ML: Conceptualization, Writing – original draft, Writing – review & editing. SS: Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

ML was employed as a Performance Psychology Consultant at Learn To Improve, https://www.learntoimprove.dk/.

The remaining 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

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Appendix

APPENDIX 1: Interview guide.

Opening questions

- Can you tell us a little about yourself?
  - Interests
  - Education
  - Job
- Can you briefly describe your football career?
  - Clubs
  - Circuit layers
  - National team
  - Role in respective teams

Theme 1: Skill development in football

- What skills do you think are required to take the step to become a professional footballer?
  - Technical factors
  - Social factors
  - Psychological factors
  - Physical factors
- Do you feel that some skills are more important than others for your development as a player?

Theme 2: Mental processes

- What do the words mental processes mean to you?
  - In everyday life
  - In football

(Interviewer defines mental processes).

- Do you consciously and actively use mental processes in your everyday training and competition?
  - Which – any special techniques?
- Where did you possibly learn or hear about these?
  - Alone or as a club
  - During battle
  - Mental toughness – own definition followed by common definition
  - Self-regulation – own definition followed by common definition
- Voltage regulating techniques
  - Self-confidence – own definition followed by shared definition
- Others?
- Do you think that mental processes are important for the level you play at today?
  - Which ones?
  - In what way?
- Which mental skills do you think are most important to have as a footballer?
- When is it most important for you to be aware of mental processes?
- Injuries
  - Out of the team
  - Fixed on the team
  - Training
  - Struggle
  - Media
- What/who is most important to your development/use of mental processes?
  - Yourself
  - The coach
  - Family and friends
  - The player group
  - Support device
  - Other?
- Are mental processes something you spend time talking about in the player group?
  - Consciously/unconsciously

Theme 3: The relationship between mental processes and performance

- How do you experience the relationship between mental processes and performance in your training everyday competition?
  - Are you aware of whether the mental affects your performance?
- If you/you have had a mental coach - how can that person help with improve your mental skills?
  - Have you had a response or benefit from this training?
- Does your role in the team have an impact on how the mind affects your performance?
  - Age
  - Experience
  - In and out of the team
  - Injuries
- If you have played in several clubs and teams; have you experienced differences in how mental processes affect your performance based on where you are and who you are with?
  - Age-specific teams
  - Circuit team/national team
  - A-team/B-team
  - Various leagues
  - Different player groups
  - Different trainers
  - Have you worked differently in the clubs with mental processes?

Closing question

- Something you would like to add about the topic that you have not been told in this interview?

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Exploring the association of mindfulness, confidence, competitive state anxiety, and attention control in soccer penalty shootouts

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Introduction: Penalty shootouts are a pivotal factor influencing outcomes in soccer matches. Soccer players face the challenge of overcoming physical fatigue and psychological pressure when taking penalty kicks. Instances of low confidence and competitive state anxiety during matches exacerbate the detrimental impact on attention control, particularly in non-target defined features, leading to suboptimal performance during penalty kicks.

Methods: This cross-sectional survey investigates the relationship between mindfulness and attention control. Convenient sampling was employed to gather a sample of 266 soccer players from sports teams and training bases in Central and South China who had participated in city-level or higher-level competitions. A structural equation model, created using AMOS 26, was employed for hypotheses validation.

Results: Findings reveal a positive correlation between mindfulness and confidence, and a negative correlation between mindfulness and competitive state anxiety. Additionally, confidence positively associates with attention control, while competitive state anxiety shows a negative relationship with attention control. Confidence and competitive state anxiety also function as mediators in the correlation between mindfulness and attention control. To elaborate, soccer penalty kickers with heightened mindfulness demonstrate increased confidence levels, reduced competitive state anxiety, and improved attention control.

Discussion: Mindfulness training positively influences attention control during penalty kicks for soccer players. To boost players' confidence, alleviate competitive state anxiety, and enhance their performance during penalty shootouts, it is recommended that governments increase investment in mindfulness training and talent development. Coaches should enhance their understanding of mindfulness training mechanisms, and athletes themselves should prioritize mindfulness training.

KEYWORDS

soccer penalty shootout, mindfulness, confidence, competitive state anxiety, attention control

1 Introduction

Football is hailed as the world's foremost sport, boasting immense influence and a vast number of fans. In terms of commercial value and revenue, football rightfully deserves the title of the world' premier sport. In football matches, penalty shootouts are the most riveting and thrilling moments. Whether it' a penalty awarded during regular time or one taken during the decisive phase of a penalty shootout, both can directly impact the final result of the game and even determine the winner (Tuğlu et al., 2022).

Players shoot from the penalty spot, situated 11 meters (12 yards) from the midpoint between the two goalposts, aiming at a goal that is 7.32 meters (8 yards) wide and 2.44 meters (8 feet) high. Various observational studies, including video analysis of proficient penalty referees, qualitative studies interviewing expert referees, and laboratory-based experiments, indicate associations between certain behaviors and psychological variables and successful performance in football penalty shootouts (Wood et al., 2015). For example, Hill and Shaw (2013) conducted a study using a six-step approach (including crowd noise simulation, self-threat, coach evaluation, enforced targets, informing goalkeepers of the shot direction) to replicate real-world stressors and explore football players' performance under high and low-pressure conditions. The study found that individual responsibility within the team (i.e., closed skills) often led to self-threat, making players perceive the most pressure (Hill and Shaw, 2013). As players walked away from midfield, the intensity of cognitive anxiety increased with perceived pressure, leading to more distractions (e.g., more thoughts about needing to score). When goalkeepers were informed of the shot direction for the last two penalty kicks, players perceived greater pressure, leading to a skill-focused attention, and their first shot performance was notably worse than their second consecutive shot, with the fourth shot showing a significant failure rate. Jordet et al. (2007) explored the impact of factors such as handling pressure, skill level, physical fatigue, and opportunities (e.g., goalkeeper movement direction) on football players' performance in penalty shootouts during major international events from 1976 to 2004. The results suggested a negative correlation between the importance of the kick (handling pressure) and the outcome, while the correlation between skill level, fatigue, and the result was minimal or insignificant. In the study by Brinkschulte et al. (2023), an analysis of 1,711 penalty kicks taken during major international tournaments over 15 years revealed that high situational pressure increased the probability of completely missing a penalty by about 6%, regardless of the player's skill level. Conversely, when a highly skilled player took the shot, the likelihood of the goalkeeper saving the penalty decreased by approximately 4%. The study concluded that high situational pressure reduces the probability of a successful penalty, while high skill level serves only as a buffer to mitigate the adverse effects of performance pressure. The extent to which these adverse factors, arising from the pressure of the game, affect football players depends largely on how they handle such situations (Ellis and Ward, 2022).

Penalties constitute a duel between the kicker and the goalkeeper, both attempting to anticipate each other's intentions to secure victory (Wood and Wilson, 2010). Van Der Kamp (2006) conducted a live simulation experiment, examining the relative advantage of kickers adopting goalkeeper-independent and goalkeeper-dependent strategies during penalty kicks. Participants using the goalkeeper-independent strategy maintained a constant visual target, while those using the goalkeeper-dependent strategy predicted the goalkeeper's save direction at different times before ball contact. The experiment results indicated that predicting goalkeeper actions increased the risk of missed shots, mainly due to continuous monitoring of goalkeeper actions, diverting attention from the ball, especially given the brief time available to adjust penalty kicks (Van Der Kamp, 2006). The phenomenon can be explained by spatial attention mechanisms (Shepherd et al., 1986). In other words, when observers search for specific targets in a visual scene, they typically direct attention toward items with known features, effectively concentrating attention (Bacon and Egeth, 1994). However, when ignored irrelevant stimuli capture attention, it can lead to impaired target detection (Folk et al., 2002). Especially in situations of match anxiety, penalty kickers may struggle to completely disregard the goalkeeper's presence, focusing more on threatening stimuli posed by the goalkeeper, thereby compromising the original attention control system (Wilson et al., 2009). Therefore, penalty kickers need to establish attention control settings representing known attributes of the target to effectively guide attention to items with target-defining features.

Psychological traits (e.g., strong confidence, focused attention) and psychological skills (e.g., maintaining confidence, re-focusing attention) are crucial factors for promoting athletes' optimal performance (Holland et al., 2010). Research indicates that mindfulness positively affects maintaining attention (Baltar and Filgueiras, 2018), enhancing attention control, reducing the risk of injuries in football players (Naderi et al., 2020), and lowering sports anxiety levels (Zadkhosh et al., 2018). Currently, mindfulness practices serve as a training method to improve athletes' psychological skills (Birrer et al., 2012). For example, Mindfulness-Acceptance-Commitment (MAC) interventions, rooted in acceptance and commitment therapy, indirectly enhance athletes' self-evaluation in sports training by refining mindfulness and emotion regulation, leading to improved sports performance (Josefsson et al., 2019). Norouzi et al. (2020) implemented an 8-week mindfulness-based stress reduction intervention for outstanding Iranian football players, finding that mindfulness training increased psychological flexibility in guiding attention, leading to increased efficiency in coping strategies and behavioral response flexibility for high-skill demand situations. Thus, in penalty situations, mindfulness is precisely the cognitive process football players need to cultivate.

Reviewing past research reveals that obstacles to football players' penalty success mainly focus on the impact of skill tactics and other strategies, such as kicking motion (Lopes et al., 2014), ball contact area (Ishii et al., 2012), and penalty strategy (Noël et al., 2015). However, there is relatively less research on how psychological factors affect football players' penalty performance. As a result, this study sets forth the following research objectives: (1) examine the correlation between mindfulness and football players' confidence and competitive state anxiety during penalty kicks; (2) investigate the relationships between mindfulness and attention control in football players; (3) explore whether and how confidence, competitive state anxiety, and attention control interact; (4) provide recommendations for addressing psychological issues in football players during penalty kicks.

This study focuses on football players, considering the influence of attention control on the psychological pressure of penalty kicks and proposing mindfulness as an intervention to alleviate attention control. The specific pathway of analysis is as follows: mindfulness training (e.g., mindfulness-acceptance-commitment, mindfulness-based stress reduction, mindfulness meditation) is conducive to promoting football players' optimal performance, thereby enhancing their self-acceptance. Confidence contributes to the emotional intelligence development of football players and reduces competitive state anxiety, thereby improving attention control during penalty kicks.

2 Literature review and hypotheses development

2.1 Mindfulness, confidence, attention control

Mindfulness is defined as the intentional maintenance of attention in the present task, non-judgmentally monitoring internal stimuli and external stimuli (Baer, 2003). Mindfulness features are described as observing or having a clear awareness of each presented experience (Creswell, 2017). Mindfulness interventions within clinical contexts predominantly involve mindfulness-based interventions and therapies (Orzech et al., 2009). Mindfulness training in Western healthcare is utilized to treat psychological disorders like depression and anxiety (Aherne et al., 2011). Similarly, mindfulness reduces perceived pressure and trait anxiety in choking athletes (Tang et al., 2023).

Confidence is a psychological structure that influences whether athletes succeed or not in sports (Short and Short, 2005). Specifically, it is a personality trait, reflecting trust in one's ability to achieve a certain goal (Shrauger and Schohn, 1995). Lack of confidence leads to physiological reactions under the emotion of fear of performing poorly and failing, often diminishing the likelihood of success, especially in crucial performances, such as lawyers presenting cases to the Supreme Court, professional golfers approaching a game-winning shot, or penalty kickers (Compte and Postlewaite, 2004). Anari and Shafiei (2016) conducted a study with students from Azad University in Kerman city. The findings revealed a notable disparity in confidence scores between participants before and after the test, underscoring the pivotal role of mindfulness in augmenting confidence. Walker (2019) measured character mindfulness, psychological resilience-related confidence, and negative self-evaluation in provincial adolescent female field hockey players. Analyzing the correlation coefficients among variables, Walker concluded that character mindfulness was positively correlated with psychological resilience confidence in adolescent athletes, with self-evaluation as the mediator. Oguntuase and Sun (2022) identified self-control as an intermediary variable between mindfulness and confidence by conducting an 8-week mindfulness-acceptance-commitment intervention on elite football players, with a control group. The results revealed that mindfulness had a significant direct and indirect correlation with enhancing football players' confidence. Therefore, this study proposes Hypothesis 1:

> *Hypothesis 1 (H1): There is a positive correlation between mindfulness and confidence.*

Attention control is typically perceived as a comprehensive process where external stimuli either attract or distract attention or are suppressed. Hakim et al. (2021) offer instances from driving, such as pertinent external cues like flashing warning signs or extraneous external distractions like flashing colored billboards, accompanied by pertinent experiments. These exemplify how attention control mechanisms assist in discerning which new information integrates with our ongoing working memory task, allowing attention to stay concentrated on the initial task. Individuals with poor attention control are more susceptible to anxiety and emotional distraction, attentional bias toward threatening stimuli, or efficiency deficits, especially in cognitive and motor performance (Young and Ellmers, 2022).

On the other hand, individuals possessing confidence tend to exhibit heightened proficiency and effectiveness in deploying the cognitive resources indispensable for attaining success in the realm of sports. This is because confident individuals can control attention in the problem-solving process when facing obstacles, while less confident individuals are more likely to focus on perceived imperfections for self-diagnosis (Hays et al., 2009). Tomé-Lourido et al. (2019) found that when athletes realize their performance does not meet activity requirements, confidence levels decrease. Their experimental research demonstrated a positive relationship between confidence and attention. Therefore, athletes can refocus skills by strengthening the relationship between attention control and confidence, avoiding choking. Junli et al. (2021) conducted a questionnaire survey on Chinese university students and, through smart-PLS analysis, proved a positive correlation between self-confidence and attention control among Chinese athletes. Self-motivation plays a significant moderating role between confidence and attention control. Therefore, this study proposes Hypothesis 2:

> *Hypothesis 2 (H2): There is a positive correlation between confidence and attention control.*

2.2 Mindfulness, confidence, competitive state anxiety, attention control

Mindfulness training can shift attention from the subjective evaluation of negative emotions to the fluctuation of bodily sensations, reducing the intensity of negative emotions such as fear and anxiety, and promoting psychological wellbeing (Farb et al., 2010). Previous studies often posit that competitive state anxiety in sports arises primarily from the perception of situational importance and the pressure generated by the uncertainty of outcomes. Competitive state anxiety exhibits a multidimensional nature, encompassing somatic anxiety characterized by physiological responses like increased heart rate and sweating, cognitive anxiety involving aspects such as self-doubt and fear of failure, and confidence entailing elements like reassurance and a sense of security (Eys et al., 2003). Cognitive anxiety embodies the psychological dimension of anxiety, entailing worry, negative self-talk, and distressing visual imagery. Conversely, somatic anxiety encompasses the physiological or emotional aspect, triggering responses like an accelerated heart rate, breathlessness, cold, and sweaty hands, as well as muscle tension (Burton, 1988). The multidimensional anxiety theory predicts that athletes' expectations of success remain stable over time, with cognitive anxiety and confidence expected to remain stable in the period before the competition. However, as the competition approaches, somatic anxiety is anticipated to rapidly increase (Krane, 1994). Previous research suggests that mindfulness has anti-depressive and anti-anxiety effects. Interventions are effective in significantly alleviating overall psychological distress, particularly symptoms related to anxiety (Marchand, 2012).

Moreover, Tang et al. (2022), focusing on recovering athletes, found that mindfulness can reduce anxiety and fatigue when facing pressure, showing a significant negative correlation between them, particularly in athletes recovering from injuries. The analysis revealed a negative correlation between mindfulness and competitive state anxiety. Additionally, the implementation of mindfulness interventions holds promise in reducing competitive state anxiety among athletes (Li et al., 2023). Quantitative experiments on karate athletes demonstrated that Mindfulness-based sport performance enhancement training reduced competitive state anxiety, with anxiety reduction accompanied by increased confidence (Harita et al., 2022). Therefore, this study proposes Hypothesis 3:

> *Hypothesis 3 (H3): There is a negative correlation between mindfulness and competitive state anxiety.*

Furthermore, athletes and coaches across various sports need to be attentive to the influence of anxiety and confidence levels on athlete performance (Habibi et al., 2017). Anxiety is typically categorized into trait anxiety, reflecting general anxiety features in personality, and state anxiety, representing temporary responses to specific situations (Endler and Kocovski, 2001). Competitive state anxiety is anxiety experienced by athletes in competitive situations, and it may be alleviated as athletes' confidence levels increase. Past research has validated this, such as Finkenberg et al. (1992), who tested competitive state anxiety in cheerleading team members participating in the national university championships before the competition. The study delved into the intricate interplay between competitive state anxiety and the psychological as well as physiological dimensions of confidence, revealing a noteworthy negative correlation between competitive state anxiety and confidence. Chapman et al. (1997) concentrated on taekwondo athletes, employing a multivariate analysis of variance to assess Competitive State Anxiety Inventory-2 scores. The findings indicated that winners exhibited elevated confidence scores and lower competitive state anxiety scores compared to losers. In a recent investigation involving basketball players, Chun et al. (2022) probed the mediating impact of sports confidence on the association between competitive state anxiety and perceived performance. Their findings brought to light a negative correlation between confidence and competitive state anxiety. Consequently, Hypothesis 4 is postulated in the context of this investigation:

> *Hypothesis 4 (H4): There is a negative correlation between confidence and competitive state anxiety.*

Attention control theory posits that anxiety reduces attention to the current task, increases attention to threat-related stimuli, and impairs attentional control (Eysenck et al., 2007). This theory is based on the assumptions of goal-directed attentional systems and stimulus-driven attentional systems (Coombes et al., 2009). Walker (2019) explored the impact of anxiety-induced attention changes on penalty kick performance, finding an increased influence of stimulus-driven attentional control systems during penalty kicks. Athletes under anxiety earlier or more intensely focused on salient stimuli, neglecting goal-driven and task-relevant stimuli, resulting in decreased attentional control and shooting performance. Presently, there is scarce research exploring the association between competitive state anxiety and attention control. Nevertheless, Tomé-Lourido et al. (2019), in their experimental investigation involving Spanish athletes, not only validated the previously mentioned positive correlation between confidence and attention control but also illustrated a negative correlation between competitive state anxiety and attentional control. Drawing from the attention control theory and the dynamics of penalty kicks, this study posits the Hypothesis 5.

> *Hypothesis 5 (H5): There is a negative correlation between competitive state anxiety and attention control.*

2.3 The mediating roles of confidence and competitive state anxiety

Previous research indicates a close association between mindfulness and the improvement of attention control (MacDonald and Olsen, 2020). Mindfulness awareness is beneficial for maintaining sustained attention on a designated task and consciously shifting attention focus in the presence of distracting stimuli to maintain the current task (Chambers et al., 2008). Preliminary evidence suggests that mindfulness's positive effects on emotional regulation and self-control can be realized by suppressing athletes' negative emotions, reducing the cyclical nature of athlete anxiety (Friese et al., 2012). Mindfulness-acceptance-commitment intervention has been shown to effectively enhance athletes' confidence (Oguntuase and Sun, 2022). Research indicates that athletes with lower confidence levels experience higher levels of competitive state anxiety (Harita et al., 2022), and lower levels of attention control (Junli et al., 2021). Individuals experiencing anxiety often exhibit heightened focus on processing threatening stimuli. This disruption leads to a decrease in attentional control, contributing to the phenomenon of choking (Clarke and Todd, 2021). Therefore, this study hypothesizes whether mindfulness can influence attention control through the mediating roles of confidence and competitive state anxiety (Figure 1). Based on this premise, the study proposes Hypothesis 6:

> *Hypothesis 6 (H6): Confidence and competitive state anxiety mediate the relationship between mindfulness and attention control.*

3 Materials and methods

3.1 Procedure

This study targeted football players in the Central and Southern regions of China who had engaged in city-level or higher-level competitions and experienced penalty kicks or penalty shootouts during matches. It employed a combination of purposive and convenience sampling approaches. The researchers, during October to November 2023, briefed team leaders and coaches at various sports teams and training facilities in the Central and Southern regions about the purpose and nature of the study. They were requested to

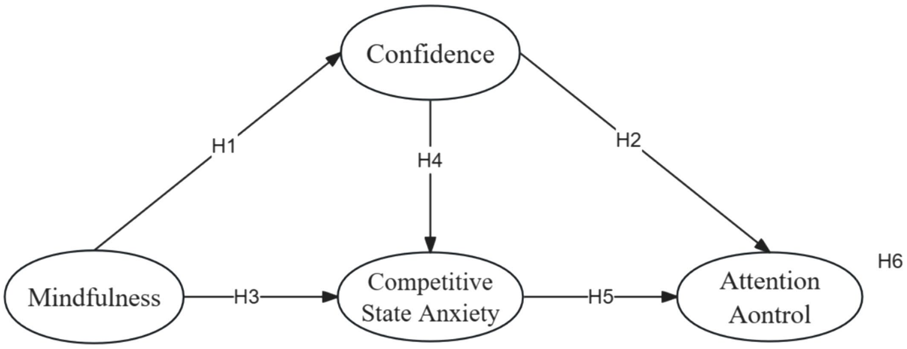

FIGURE 1
The conceptual framework.

communicate the study's objectives to the athletes and distribute the questionnaire among them once informed. Additionally, athletes were encouraged to share the questionnaire with their peers. Distributing a total of 300 questionnaires resulted in the collection of 266 valid responses, establishing an effective response rate of 88.7%.

Table 1 displays the demographic characteristics of the 266 athletes surveyed. Findings from the study indicate that: (1) nearly half of the surveyed individuals fall within the age range of 18–25 years. (2) The majority of participants in the study are male football players (55.4%), slightly outnumbering their female counterparts (44.6%). (3) More than half of the football players are university students. (4) In terms of skill level, close to half of the athletes (50.7%) are at the level of football players, with a small proportion (4.3%) reaching the level of elite athletes. (5) Over half of the football players have taken penalty kicks in game situations more than 10 times. (6) Approximately half of the football players participate in competitions at the provincial level (48.5%), with a smaller percentage (16.2%) competing at the national level.

TABLE 1 Characteristics of participants ($N = 266$).

Profiles	Survey (%)
Age	
18–25	151 (56.7%)
26–35	98 (36.8%)
≥36	17 (6.5%)
Gender	
Male	153 (57.6%)
Female	113 (42.4%)
Education level	
Below high school	17 (6.4%)
High school/vocational school	97 (36.3%)
College and above	152 (57.3%)
Sport level	
No sports grade certificate	119 (44.7%)
Second-level athlete	91 (34.2%)
Tier 1 athlete	46 (17.2%)
National athlete level	10 (3.9%)
Number of penalties	
1–5	51 (19.1%)
6–10	62 (23.3%)
11–15	68 (25.6%)
≥16	85 (32%)
Event level	
Municipal level	94 (35.3%)
provincial	129 (48.5%)
National level	43 (16.2%)

3.2 Measures

The survey employed in this study is composed of five sections, encompassing a total of 23 items. The initial segment of the questionnaire involved respondents furnishing demographic information such as age, gender, educational level, and sports proficiency. Subsequently, the second section gaged respondents' mindfulness levels utilizing the five items from the Sport Mindfulness Scale (Thienot et al., 2014). Sample items include "I am able to notice the intensity of nervousness in my body." In the third section, data on respondents' self-esteem levels were gathered using four items from the Rosenberg Self-Esteem Scale (Heatherton and Wyland, 2003). An example item is "On the whole, I am satisfied with myself." In the fourth section, participants' competitive state anxiety was assessed using the revised Competitive State Anxiety-2 Scale (Martinent et al., 2010), which includes five items. Sample items include the statement "I feel self-confidence." Lastly, the fifth section gathered data on respondents' attention control using five items from the Attention Control Scale (Fajkowska and Derryberry, 2010). Sample items, such as "When trying to focus my attention on something, I have difficulty blocking out distracting thoughts." were included. All four scales were assessed using a five-point Likert scale.

Pilot testing was then carried out to verify the reliability of the adapted survey instrument. Utilizing convenience sampling, 60 questionnaires were distributed to high-level university athletes in a specific city, resulting in 56 valid responses (Kimberlin and Winterstein, 2008). The outcomes revealed that Cα coefficients for all scales surpassed 0.9, denoting excellent internal consistency (Fornell and Larcker, 1981).

3.3 Data analysis

In this study, version 26.0 of AMOS was harnessed to construct a robust structural equation model (SEM) that delves into how mindfulness contributes to enhancing attention control among soccer penalty kick players. Adhering to the two-step modeling approach advocated by Anderson and Gerbing (1988), the evaluation encompassed both the measurement model and the structural model. Following a meticulous scrutiny of reliability and validity, the analysis proceeded to gage the fit and path coefficients of the hypothesized model while scrutinizing the presence of intermediate effects.

To address common method variation (CMV), this study implemented the recommended methodology, contrasting the chi-square values and degrees of freedom (df) between a single-factor model and a multifactor model. The results unveiled that the chi-square for the single-factor model was 1092.442 (df = 152, $p < 0.001$). In stark contrast, the chi-square for the multifactor model was 171.116 (df = 146, $p < 0.001$). This comparison indicates that the fit of the single-factor model aligns with that of the multifactor model. The outcomes strongly imply the absence of a single-factor structure, affirming that CMV exerts a negligible impact on this study and can be dismissed.

4 Results

4.1 Measurement model

In this study, the assessment of the reliability and discriminant validity of latent variables involved the calculation of Cα and CR coefficients. Table 2 presents the Cα coefficients, ranging from 0.834 to 0.901, with all CR values surpassing 0.8 for each variable. Moreover, the average variance extracted (AVE) for each variable fell within the range of 0.559–0.646. This indicates that all variables exhibited high reliability and convergent validity. Additionally, as per Table 3, all inter-variable correlation coefficients were below the square root of AVE, signifying outstanding discriminant validity among all variables.

TABLE 2 Reliability and validity.

Items	Loadings	Cα	AVE	CR
Mindfulness (MIN)		0.901	0.646	0.901
MIN1	0.818			
MIN2	0.818			
MIN3	0.825			
MIN4	0.783			
MIN5	0.774			
Confident (CON)		0.834	0.560	0.835
CON1	0.807			
CON2	0.716			
CON3	0.677			
CON4	0.787			
Competitive state anxiety (CSA)		0.868	0.559	0.863
CSA1	0.754			
CSA2	0.770			
CSA3	0.815			
CSA4	0.758			
CSA5	0.628			
Attention control (AC)		0.867	0.570	0.868
AC1	0.785			
AC2	0.724			
AC3	0.788			
AC4	0.787			
AC5	0.684			

TABLE 3 Evaluation of discriminant validity.

Construct	MIN	CON	CSA	AC
MIN	**(0.804)**			
CON	0.379 **	**(0.748)**		
CSA	−0.410 **	−0.533 **	**(0.748)**	
AC	0.429 **	0.551**	−0.508**	**(0.755)**

The diagonals of the matrix display the square root of the average variance extracted (bold), while off-diagonals represent Pearson's correlation coefficients. ** $p < 0.01$.

4.2 Hypothesis testing

The structural equation model demonstrated robustness as evidenced by high goodness-of-fit indices (χ^2/df = 1.218, GFI = 0.934, AGFI = 0.915, NFI = 0.936, RMSEA = 0.029), surpassing recommended thresholds significantly. The Pearson correlation results in Table 3 revealed significant correlations among the independent, mediating, and dependent variables, thereby supporting the hypotheses.

The structural path model illustrated in Figure 2 revealed statistically significant relationships: the association between mindfulness and confidence was found to be significant ($\beta = 0.468$, $p < 0.001$), confirming H1; the relationship between mindfulness and competitive state anxiety was significant ($\beta = -0.234$, $p < 0.001$), supporting H2; the connection between confidence and competitive state anxiety was significant ($\beta = -0.503$, $p < 0.001$), substantiating H3; the association between confidence and attention control was significant ($\beta = 0.465$, $p < 0.001$), validating H4; and the link between competitive state anxiety and attention control was significant ($\beta = -0.307$, $p < 0.001$), affirming H5.

Hypothesizing that mindfulness influences soccer players' attention control through the mediating pathways of confidence and competitive state anxiety, researchers employed Bootstrap resampling (5,000 samples) to scrutinize the mediation effects. The standardized results, along with a 95% confidence interval, are presented in Table 4. Notably, the Z-statistic absolute value for the MIN → AC mediation effect surpassed 1.96, indicating the exclusion of 0 within the 95% confidence interval.

Furthermore, the association between mindfulness and attention control was significantly influenced by both confidence and competitive state anxiety (standardized indirect effect = 0.362, $p < 0.001$), corroborating H6. These results suggest that soccer players exhibiting higher levels of mindfulness, increased confidence, and

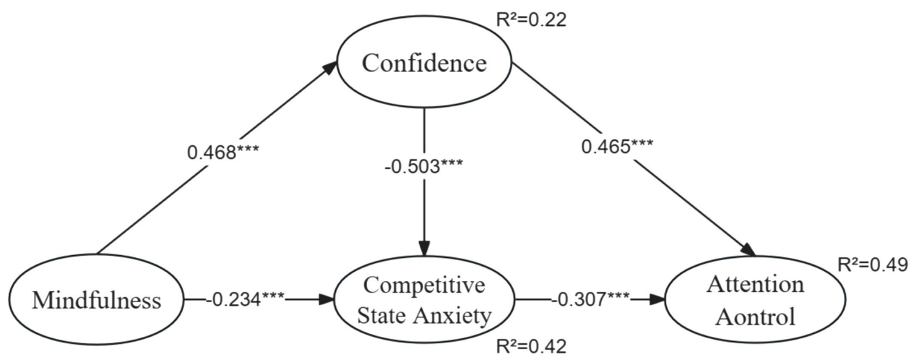

FIGURE 2
Structural model. ***$p < 0.001$.

TABLE 4 Indirect effects.

	Point estimate	Product of coefficients		Bootstrapping		
				Bias-corrected 95% CI		Two-tailed significance
		SE	*Z*	Lower	Upper	
MIN → AC	0.362	0.052	6.96	0.258	0.459	< 0.001

decreased competitive state anxiety showcase improved attention control during penalty shootouts.

5 Discussion

5.1 Theoretical contribution

Firstly, existing research primarily focuses on the technical aspects (Lopes et al., 2014), target selection (Ishii et al., 2012), and strategies (Noël et al., 2015) during penalty kicks, with limited attention to the players' attention control. This study addresses the issue of attention control among soccer players during penalty kicks, providing a more targeted perspective and enriching the relevant theoretical research. In soccer matches, scoring against the opponent within regular match time is challenging, involving intense physical confrontations and long-distance running. Whether it is a referee-awarded penalty or a penalty shootout, players have only a brief time to recover from physical and cognitive fatigue.

In high-pressure situations like a decisive penalty kick, players often struggle to adjust their confidence levels and manage competitive state anxiety when facing the goalkeeper. It is widely believed that selecting information from visual displays is controlled by both goal-directed and stimulus-driven mechanisms (Yantis, 1993). Anxious penalty takers are more influenced by the stimulus-driven attention control system, excessively focusing on the threatening goalkeeper, which can cause their shot to deviate from the intended target (Wilson et al., 2009). Additionally, studies have shown that confidence has a positive impact on sports performance, with a stronger relationship between confidence and performance in short-duration sports compared to long-duration sports (Lochbaum et al., 2022). This can be explained by spatial attention mechanisms: visual attention can be guided voluntarily or goal-directed by observers, or it can be stimulus-driven by attention capture (Serences et al., 2005).

Research indicates a positive correlation between confidence and attention control, and a negative correlation between competitive state anxiety and attention control, validating hypotheses H2 and H5. In other words, in high-pressure situations, it is more beneficial for penalty takers to maintain high confidence and low competitive state anxiety to increase their chances of success. Moreover, good psychological skills are crucial for successful penalty kicks (Junge et al., 2000). Considering the close relationship between threatening stimuli (e.g., negative emotions during the kick, the goalkeeper, noisy crowds) and optimal performance during penalties, as well as the tendency for distraction during the penalty moment to result in suboptimal performance, this study explores the necessity of interventions involving mindfulness and confidence to impact competitive state anxiety and attention control in football players.

The findings reveal a positive correlation between mindfulness and confidence and a negative correlation with competitive state anxiety (refer to Figure 2), aligning with the results observed by Oguntuase and Sun (2022) and Tang et al. (2022). Notably, mindfulness exerts the most significant influence on competitive state anxiety, followed by confidence. Thus, hypotheses H1 and H3 are supported. Penalty takers with mindfulness techniques are better equipped to quickly overcome confidence issues and anxiety, maintaining focused attention at the moment of the shot. Similarly, consistent with the studies by Finkenberg et al. (1992) and Chapman et al. (1997), this study found a negative correlation between confidence and competitive state anxiety, validating hypothesis H4. As the confidence level of penalty takers increases, symptoms of competitive state anxiety decrease.

Additionally, both confidence and competitive state anxiety act as mediators in the relationship between mindfulness and attention control. As illustrated in Figure 2, these variables collectively explain

49% of the variance in attention control, confirming hypothesis H6. The study thus offers a valuable pathway for exploring the connection between mindfulness and attention control, particularly by investigating the role of mindfulness intervention, starting from the lack of confidence and the occurrence of competitive state anxiety in penalty-taking soccer players.

5.2 Practical implications

The study highlights the significant correlation between mindfulness and the confidence and competitive state anxiety of soccer penalty kick-takers. It establishes a positive association between mindfulness and confidence and a negative association with competitive state anxiety. Furthermore, the research reveals how confidence and competitive state anxiety play a mediating role in the relationship between mindfulness and attention control. Given the myriad internal and external challenges faced by soccer penalty kick-takers during matches, coupled with the prevalence of unsuccessful penalties in soccer and their potential repercussions on athletes' psychological wellbeing and performance, mindfulness emerges as a pivotal factor warranting consideration. In light of these insights, this study suggests that training facilities and coaches incorporate mindfulness training for soccer players to cultivate and enhance their mindfulness skills. Integrating mindfulness practices, such as meditation, into athletes' training and pre-and post-match routines may improve confidence and effectively manage competitive state anxiety. These positive mindfulness interventions can also benefit athletes in other sports, particularly those susceptible to the influences of diminished confidence and anxiety, such as penalty takers or shooters. Thus, emphasizing the elevation of mindfulness training, especially for athletes displaying high levels of lack of confidence and anxiety, is essential.

However, the current status of mindfulness training for athletes in China is not ideal. This situation results from various factors, including coaches' limited understanding of the principles and mechanisms of mindfulness training, inadequate training facilities, and a lack of professional mindfulness guidance courses. To address these challenges, the study proposes a series of feasible recommendations. To the government, it is recommended that the General Administration of Sport and relevant departments acknowledge the beneficial impacts of mindfulness on confidence, competitive state anxiety, and attention control. They should establish a professional system for training coaches in mindfulness, integrate relevant mindfulness training courses into university talent development programs, and increase the proportion of professionals proficient in mindfulness training. Simultaneously, greater financial investment in mindfulness training, designating some universities as mindfulness training and assessment bases, increasing the availability of related equipment, and establishing a mutually beneficial model between universities and soccer training facilities can be considered. Long-term monitoring and assessment of athletes' psychological states by universities can enable coaches to develop more tailored training plans based on athletes' specific conditions, further promoting the psychological health of soccer players.

Similarly, for coaches, enhancing their understanding of the principles and mechanisms of mindfulness training, as well as comprehending how mindfulness affects performance and reinforcing their grasp of mindfulness training methods, is crucial. Research has shown that mindfulness meditation practice is associated with improved attention control, with the shortest effective duration being 60 days. Additionally, the benefits of this practice tend to increase over time (Baltar and Filgueiras, 2018). Therefore, it is worth normalizing mindfulness meditation practice and integrating it into daily training routines. Furthermore, studies have demonstrated that the effectiveness of mindfulness interventions can be identified through monitoring cortisol levels and conducting continuous performance tests and attention capture tests (Meland et al., 2015). Coaches should prioritize athletes' mental and physical health, promptly understanding their physical and mental states, analyzing them, and formulating corresponding improvement methods.

Recently, Vella-Fondacaro and Romano-Smith (2023) proposed a combined psychological skills training and mindfulness-based intervention program (PSTMI), with each session lasting 30 min. This program includes goal setting, imagery, arousal regulation, mindfulness practice, and self-talk, which are beneficial for better attention control and overall performance. In training and competition, coaches need to reasonably arrange the content of psychological skills training according to the training phase and competition level. For example, goal setting and imagery should be introduced early in pre-competition preparation to maintain athletes' mental health, while mindfulness/arousal regulation and self-talk should be utilized during more challenging competitions to help athletes overcome the impact of threatening stimuli on their attention control.

According to the confirmed outcomes indicating that confidence and competitive state anxiety play a mediating role in the connection between mindfulness and attention control, athletes themselves should actively strive to deepen their comprehension of mindfulness principles. During mindfulness training, athletes should purposefully enhance their present-moment awareness, accept thoughts and emotions, and avoid reacting to stressors, to maintain focused attention during high-pressure penalty situations. In daily training, athletes should practice mindful meditation, focusing their thoughts on a single target, usually their breath, with firmness and clarity to achieve a calm mind and sustained concentration.

During competitions, especially before taking penalty kicks, athletes should utilize psychological skills such as mindfulness/arousal regulation and self-talk to overcome lack of confidence and competitive state anxiety when facing the goalkeeper, keeping their attention on the task at hand. Simultaneously, athletes should earnestly listen to and implement mindfulness techniques provided by coaches and psychological monitoring organizations to help overcome lack of confidence and competitive state anxiety, thereby improving attention control levels during penalty kicks.

6 Limitations

Firstly, the research model did not account for moderating variables such as athletes' personalities and training levels. Future research should delve into potential variations and developments in the model. Secondly, the sample size only included soccer players from training bases and teams in the Central and South China regions. Consequently, the study results may not be extrapolated to more advanced soccer player cohorts or other sports. Subsequent research should encompass diverse levels of soccer populations, such as female soccer players or athletes from different sports. Lastly, due to the adoption of a cross-sectional design rather than an experimental longitudinal approach, the study's breadth and depth are constrained. Future research could consider measuring pre-match, post-match, and in-match confidence and competitive state anxiety, dividing the samples into two groups, thereby enhancing the scientific rigor of the study.

7 Conclusion

Aligned with the research objectives, this study suggests that a significant portion of soccer players, when confronted with penalty kicks, can augment their attention control by modulating levels of confidence and competitive state anxiety through mindfulness training. The findings underscore the effectiveness of mindfulness training in improving soccer players' attention control, especially under the intense pressure of penalty situations. Sustaining attention, boosting confidence, and alleviating competitive state anxiety are identified as crucial aspects where mindfulness training plays a significant role.

Mindfulness training enhances athletes' confidence and alleviates competitive state anxiety, additionally influencing attention control levels through the mediating roles of confidence and competitive state anxiety. Therefore, monitoring soccer players' ability to maintain attention under high-pressure environments through cortisol level monitoring, continuous performance tests, and attention capture tests is crucial. Implementing mindfulness meditation and mindfulness interventions can improve athletes' psychological skills to handle the lack of confidence and competitive state anxiety triggered by penalty situations. On the field, athletes should consciously practice enhancing present-moment awareness, accepting thoughts and emotions, and not reacting to stressors to improve attention control levels. This practice helps maintain focused attention at the critical moment of taking a shot.

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 Academic Committee of the School of Physical Education of Hunan University of Science and Technology (no. ECSPEHNUST 2023/0016). 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

LS: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing. LJ: Investigation, Supervision, Writing – original draft, Writing – review & editing. HW: Conceptualization, Project administration, Writing – original draft, Writing – review & editing. YL: Resources, 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

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Associations between physical activity, long COVID symptom intensity, and perceived health among individuals with long COVID

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Introduction: Physical activity (PA) is associated with better perceived health among individuals with chronic conditions. However, PA's relationship with perceived health in people with long COVID is unclear and may be modified by long COVID symptom burden.

Methods: Participants with self-reported long COVID ($N = 379$) responded to an online survey cross-sectionally assessing PA levels, perceived physical and mental health, and intensity of CDC-defined long COVID symptoms on a 0–100 scale. Linear regression analyses assessed the associations between PA and perceived physical and mental health, after accounting for sociodemographic, health behavior, and long COVID intensity variables, with *post-hoc* analyses comparing health across PA levels.

Results: Increasing levels of PA were associated with increases in perceived physical health ($\beta = 0.27$, $p < 0.001$) and mental health ($\beta = 0.19$, $p < 0.001$) after accounting for sociodemographic and health behavior variables. PA remained significantly associated with perceived physical health ($\beta = 0.15$, $p < 0.001$) but not perceived mental health ($\beta = 0.09$, $p = 0.067$) after the adding long COVID intensity to the model. Insufficiently active and active groups reported significant better physical and mental health than the inactive group ($ps < 0.05$), while the highly active group did not significantly differ from any other group on perceived physical or mental health ($ps > 0.05$). Inactive individuals reported significantly greater long COVID symptom burden compared to each other PA level ($ps < 0.05$).

Conclusion: Higher levels of PA may be associated with better physical health among individuals with long COVID, even after accounting for symptom intensity. However, long COVID symptom intensity may confound the relationship between PA and mental health among individuals with long COVID.

KEYWORDS

long COVID, post-acute sequalae of COVID-19, physical activity, exercise, physical health, mental health

Introduction

Long COVID, also called post-acute sequalae of COVID-19 (PASC), describes the experience of long-term symptoms following COVID-19 infection (Davis et al., 2023) Up to 20% of those infected with COVID-19 develop long COVID, and estimates suggest that over 65 million individuals are affected worldwide (Davis et al., 2023). Long COVID has been associated with significantly worse physical and mental health compared to the general population without long COVID (Ganesh et al., 2021; Sirotiak et al., 2023, 2024a, 2024b). Symptoms of long COVID are wide-ranging and heterogenous, complicating research and treatment efforts (Aiyegbusi et al., 2021). Long COVID is frequently diagnosed by a process of exclusion, in which other potential causes of symptoms are ruled out prior to diagnosis (Koc et al., 2022; Davis et al., 2023; Srikanth et al., 2023). Treatment options for long COVID are limited given the unclear nature of the condition and heterogenous symptom presentation (Koc et al., 2022; Davis et al., 2023). Somatic syndromes, such as fibromyalgia, myalgic encephalomyelitis/chronic fatigue syndrome (ME/CFS), and irritable bowel syndrome, describe collections of physiological symptoms that cannot be attributed to a clear organic cause (Barsky and Borus, 1999; Salari et al., 2022; Savin et al., 2023; Ursini et al., 2023). Active management strategies such as exercise and psychotherapy are common treatment strategies for these conditions, which have emerged as common comorbidities of long COVID (Henningsen, 2018; Salari et al., 2022; Savin et al., 2023; Ursini et al., 2023). Given the unclear cause of long COVID and lack of medical treatment options available, identifying self-management strategies may be particularly important to those living with long COVID.

Physical activity (PA) is one treatment strategy in the context of somatic syndromes, including long COVID, with unclear results (Twisk and Maes, 2009; Johannesson et al., 2015; Vink and Vink-Niese, 2018; Larun et al., 2019; White and Etherington, 2021). Long COVID groups undergoing exercise intervention have reported improved dyspnea, anxiety, kinesiophobia (fear of PA), muscle strength, walking capacity, quality of life, and perceived fatigue (Fugazzaro et al., 2022; Araújo et al., 2023). However, in a cross-sectional retrospective study investigating the relationship between long COVID symptoms and PA, 75% of the sample noted that PA worsened their symptoms, while just 1% reported improved symptoms following PA (Wright et al., 2022). Particularly among individuals who were physically active prior to COVID-19, a lack of ability to return to prior athletic abilities has been related to depression, suicidal thoughts, and desperation regarding a return to PA (Humphreys et al., 2021; Shelley et al., 2021). While 84% of individuals with long COVID reported meeting the PA guidelines prior to long COVID, only 8% met them at present (Wright et al., 2022).

Most studies concerning PA and long COVID have specifically considered the impact of PA on long COVID symptoms, rather than identifying the associations between PA and perceived health status (Humphreys et al., 2021; Shelley et al., 2021; Wright et al., 2022). While long COVID symptom status may be a useful consideration in tracking condition progression, perceived health may provide better information regarding the impact to the lived experience and functional abilities of each individual affected. Health perception, defined as an individual's beliefs regarding their health status, describes to what degree an individual feels they can function in physical, mental, and social domains (Kaleta et al., 2009). By considering an individual's quality of life and functional abilities, rather than just their physiological status or symptoms, the recent consideration of perceived health in medical research has been heralded as a meaningful and impactful change to health-related measurement in a variety of populations (Broderick et al., 2013). Therefore, the purpose of this study is to investigate the association of PA and symptom intensity with perceived physical and mental health among individuals with long COVID.

Method

A total of 379 adults in the United States (US) with self-reported long COVID responded to an online survey inquiring about sociodemographic characteristics, health status, psychological traits, and experiences during the COVID-19 pandemic. Participants were asked the number of times they had experienced COVID-19, either confirmed by a lab test (PCR, antigen, or other) or assumed by a healthcare provider or themselves. Individuals endorsing at least one infection were then asked whether they experienced long-term symptoms following COVID-19 infection. Participants endorsing currently experiencing long-term symptoms following COVID-19 infection were considered to have long COVID. Participants were not required to report symptoms for a specific duration of time due to the variation in the duration labeled long-term symptoms of COVID-19; instead, long COVID status was self-reported. Inclusion criteria included being over the age of 18 and US-dwelling. Participants were recruited through mass email to students, staff, faculty, and alumni at a large university, as well as posts on long COVID-specific social media sites. The study was approved by the Iowa State University Institutional Review Board and participants indicated consent prior to entering the survey.

Measures

Participant characteristics

Respondents reported age, gender identity, racial and ethnic groups, highest level of education, and annual income.

Long COVID symptom intensity

Participants endorsed long COVID symptoms currently experienced from a list of long COVID symptoms offered by the CDC (Center for Disease Control and Prevention, 2022). Participants were presented with a 0–100 scale and asked to rate the intensity of each endorsed symptom, with higher scores associated with greater severity of that symptom. Symptoms were grouped as defined by the CDC (Center for Disease Control and Prevention, 2022) into five categories: (1) general symptoms: exhaustion, tiredness, or fatigue; fever; symptoms that worsen after physical or mental effort; (2) cardiorespiratory symptoms: difficulty breathing or shortness of breath; cough; chest pain or tightness; fast heart rate or heart palpitations; (3) neurological symptoms: difficulty thinking, concentrating, or brain fog; pins-and-needles feeling (nerve pain); headache; lightheadedness or dizziness; sleep problems; changes in smell or taste; depression; anxiety; (4) digestive symptoms: abdominal or stomach pain; diarrhea; and (5) other symptoms: joint or muscle pain; rash; changes in menstrual cycle. Overall intensity ratings represented the combined symptom intensity, with the intensity of individual symptoms reported summed. Each subcategory of symptoms was also assigned an average intensity rating of endorsed symptoms within each symptom category.

Perceived physical and mental health

Perceived physical and mental health were measured with the Patient Reported Outcomes Measurement Information System (PROMIS) Global Health, version 1.2 (National Institutes of Health, 2019). Two subscale scores can be calculated from the full scale, resulting in physical and mental health subscales. Each subscale consisted of four items. Physical health questions included a question about general physical health, ability to carry out activities of daily living, average pain, and average fatigue. Mental health questions included a question about quality of life, general mental health including mood and thinking ability, satisfaction with social activities and relationships, and emotional problems. Raw scores for each subscale were converted to *T*-scores, with a mean of 50 and a standard deviation of 10, as indicated by established values for the US adult population (Northwestern University, 2023). Higher scores indicate better perceived physical and mental health. Internal consistency within the current sample was as follows: physical health $\alpha = 0.59$ ($\alpha = 0.69$ among individuals with no missingness); mental health $\alpha = 0.67$ ($\alpha = 0.75$ among individuals with no missingness). This scale has been utilized in similar chronic illness populations (Merriwether et al., 2016; Pak et al., 2021).

Physical activity level

Moderate (e.g., brisk walking) or vigorous (e.g., running) aerobic PA level was measured by inquiring about the number of minutes in an average week each participant engages in moderate or vigorous aerobic PA. Participants selected from four provided options: 0 min; 1 to <150 min; 150 to <300 min; and ≥ 300 min per week. Responses fit into established categories based on the 2018 Physical Activity Guidelines for Americans (0 min = inactive; 1 to <150 min = insufficiently active; 150 to <300 min = active; ≥300 min = highly active) (U.S. Department of Health and Human Services, 2018).

Alcohol consumption

Alcohol intake was measured, which was then converted into four categories of alcohol consumption: never, former, moderate, and excessive. Moderate alcohol consumption was considered to be 14 drinks or less per week for men, or 7 drinks or less per week for women (U.S. Department of Agriculture and U.S. Department of Health and Human Services, 2020). Excessive alcohol consumption was considered to more than 14 drinks per week for men or more than 7 drinks per week for women.

Smoking status

Participants reported whether they currently smoke cigarettes, chew tobacco, vape, or use e-cigarettes. Responses were coded dichotomously: "yes" or "no."

Sleep quality

Sleep quality was assessed with the Patient-Reported Outcome Measurement Information System (PROMIS) Sleep Disturbance Short Form 4a (PROMIS Health Organization, 2021). Respondents rate 4 items, two of which are reverse coded, on a 5-point Likert scale. Scores range from 4 to 20, with higher scores indicating greater sleep disturbance. Raw scores were translated into established *T*-scores for each participant, as recommended (PROMIS Health Organization, 2021). Internal consistency in the current sample was $\alpha = 0.62$ ($\alpha = 0.69$ among individuals with no missingness). The PROMIS sleep measures have been utilized in similar chronic condition populations (Burgess et al., 2019; Chimenti et al., 2021).

Statistical analyses

Statistical analyses were conducted in SPSS, version 27 (IBM Corp, 2020). There were no imputations performed on any scale. Sociodemographic variables (age, gender identity, racial and ethnic group, education, and income) that have been associated with long COVID were included in the regression analyses as covariates (Perlis et al., 2022; Jacobs et al., 2023). Alcohol use, smoking status, and sleep disturbance were also included as covariates due to their association with long COVID (Wickham et al., 2020; Paul and Fancourt, 2022; Subramanian et al., 2022). Gender identity, racial group, and ethnic group were dichotomized (male/female, white/non-white, not Hispanic or Latino/Hispanic or Latino) to reduce categories with a low number of participants.

Multivariable linear regression models were used to assess the association between PA level and perceived physical and mental health. Model 1 consisted of current PA level, while Model 2 added sociodemographic characteristics (age, gender identity, racial and ethnic group, education, and income). Model 3 added health behaviors (alcohol use, smoking status, sleep disturbance). *Post-hoc* comparison tests with Bonferroni adjustment assessed differences in perceived health among PA levels after accounting for sociodemographic and health behavior variables. Model 4 considered intensity of long COVID symptoms. A linear regression model with Bonferroni-adjusted *post-hoc* comparisons assessed differences in average intensity ratings for CDC-defined groupings of symptoms by PA level. Individuals with missing variables in the model were removed from that analysis. A significant level of $p < 0.05$ was utilized for each analysis.

Results

Participants were an average 41.9 (SD = 16.6) years old, and most identified as female (53.3%), white (87.9%) and not Hispanic or Latino (85.2%). Most of the sample had received at least a bachelor's degree (63.8%). More than half participants noted moderate alcohol intake (58.0%) and no smoking (68.3%). The sample reported half a standard deviation greater sleep disturbance than the U.S. general population ($T = 55.4$), and perceived physical and mental health one standard deviation worse than the U.S. general population ($Ts = 39.7$, 41.4, respectively) (PROMIS Health Organization, 2021; Northwestern University, 2023). Around half (47.5%) of the participants reported being insufficiently active. Detailed sociodemographic characteristics can be viewed in Table 1.

A linear regression model demonstrated that PA level was significantly positively associated with perceived physical health (Model 1; $\beta = 0.35$, $t(281) = 6.20$, $p < 0.001$). PA level remained

TABLE 1 Participant characteristics ($N = 379$).

	N (%)
Age M years (SD)	41.9 (16.6)
Missing	60 (15.8)
Gender identity, *N* (%)	
Male	167 (44.1)
Female	202 (53.3)
Transgender woman	3 (0.8)
Transgender man	3 (0.8)
Genderqueer/Gender-nonconforming	4 (1.1)
Racial group, *N* (%)	
White	333 (87.9)
Non-white	46 (12.1)
Ethnic group, *N* (%)	
Hispanic or Latino	43 (11.3)
Not Hispanic or Latino	323 (85.2)
Prefer not to answer/Unknown	13 (3.4)
Education, *N* (%)	
Less than high school	8 (2.1)
High school	50 (13.2)
Associate/technical degree	79 (20.8)
Bachelor's degree	152 (40.1)
Graduate school/professional	90 (23.7)
Income, *N* (%)	
Less than $16,000	41 (10.8)
$16,000 – $34,999	47 (12.4)
$35,000 – $49,999	30 (7.9)
$50,000 – $74,999	70 (18.5)
$75,000 – $99,999	59 (15.6)
Greater than $100,000	123 (32.5)
Unsure	9 (2.4)
Sleep quality, M (SD)	**55.4 (6.7)**
Missing	4 (1.1)
Alcohol consumption, *N* (%)	
Never	51 (13.5)
Former	95 (25.1)
Moderate	220 (58.0)
Excessive	13 (3.4)
Currently smoking, *N* (%)	
No	259 (68.3)
Yes	120 (31.7)
Perceived Health, M T-score (SD)	
Physical health	39.7 (7.8)
Missing, *N* (%)	1 (0.3)
Mental health	41.4 (8.1)
Missing, *N* (%)	1 (0.3)

(Continued)

TABLE 1 (Continued)

	N (%)
Physical Activity, *N* (%)	
Inactive	80 (21.1)
Insufficiently active	180 (47.5)
Active	93 (24.5)
Highly active	26 (6.9)
Combined LC intensity M (SD)	**362.3 (317.2)**
Not reported/Missing, *N* (%)	64 (16.9)
Average LC intensity per symptom group, M (SD)	
General	64.0 (23.1)
Not reported/Missing, *N* (%)	139 (36.7)
Cardiorespiratory	53.1 (23.5)
Not reported/Missing, *N* (%)	167 (44.1)
Neurological	62.9 (20.5)
Not reported/Missing, *N* (%)	129 (34.0)
Digestive	54.6 (26.0)
Not reported/Missing, *N* (%)	307 (81.0)
Other	63.1 (22.0)
Not reported/Missing, *N* (%)	230 (60.7)

[a]LC, long COVID; M, mean; *N*, number.
[b]Physical and mental health assessed through the PROMIS Global Health v1.2 scale, with converted *T*-scores reported.
[c]Sleep was measured by the PROMIS Sleep Disturbance Short Form 4a, with higher scores indicating increased sleep disturbance.
[d]Current alcohol consumption categories as determined by the Dietary Guidelines for Americans, 2020–2025.
[e]Physical activity reported via self-report of moderate or vigorous physical activity (inactive = 0 min; insufficiently active = 1 to < 150 min, active = 150 to < 300 min, highly active = ≥ 300 min).
[f]Not reported/Missing, CDC symptom or symptom group not reported or answer missing.

significantly associated with perceived physical health after accounting for sociodemographic variables (Model 2; $\beta = 0.32$, $t(281) = 5.80$, $p < 0.001$) and health behaviors (Model 3; $\beta = 0.27$, $t(281) = 5.34$, $p < 0.001$). The total intensity of CDC-defined long COVID symptoms significantly contributed to the model (Model 4; $\beta = -0.48$, $t(281) = -9.85$, $p < 0.001$). However, the association between PA level and perceived physical health remained significant after accounting for long COVID intensity (Model 4; $\beta = 0.15$, $t(281) = 3.44$, $p < 0.001$). In the sensitivity analysis, the interaction of PA and long COVID intensity on perceived physical health was not significant ($\beta = -0.11$, $t(281) = -1.06$, $p = 0.292$). Detailed results can be viewed in Table 2.

A linear regression model demonstrated that PA level was significantly associated with perceived mental health (Model 1; $\beta = 0.28$, $t(281) = 4.94$, $p < 0.001$). PA level continued to remain significantly associated with perceived mental health after accounting for sociodemographic variables (Model 2; $\beta = 0.25$, $t(281) = 4.58$, $p < 0.001$) and health behaviors (Model 3; $\beta = 0.19$, $t(281) = 3.77$, $p < 0.001$). The total intensity of CDC-defined long COVID symptoms significantly contributed to the model (Model 4; $\beta = -0.45$, $t(281) = -8.74$, $p < 0.001$). The association between PA level and perceived mental health was no longer significant after accounting for long COVID intensity (Model 4; $\beta = 0.09$, $t(281) = 1.84$, $p = 0.067$). In the sensitivity analysis, the interaction of PA and long COVID intensity on perceived mental health was not significant ($\beta = -0.10$,

TABLE 2 Multivariable linear regression of PA level and long COVID symptom intensity on physical health.

	Model 1			Model 2			Model 3			Model 4		
	B (SE)	*β*	*p*-value	*B* (SE)	*β*	*p*-value	*B* (SE)	*β*	*p*-value	*B* (SE)	*β*	*p*-value
PA level	3.53 (0.57)	0.35	**<0.001**	3.30 (0.57)	0.32	**<0.001**	2.70 (0.51)	0.27	**<0.001**	1.55 (0.45)	0.15	**<0.001**
Age (years)	–	–	–	−0.00 (0.03)	−0.00	0.981	−0.06 (0.03)	−0.12	0.052	−0.05 (0.03)	−0.10	0.065
Gender identity	–	–	–	−1.89 (0.92)	−0.12	**0.041**	−1.92 (0.84)	−0.12	**0.023**	−0.20 (0.74)	−0.01	0.786
Racial group	–	–	–	−1.21 (1.34)	−0.05	0.368	−1.26 (1.18)	−0.05	0.286	−1.33 (1.01)	−0.06	0.190
Ethnic group	–	–	–	−0.65 (1.30)	−0.03	0.618	−0.66 (1.14)	−0.03	0.563	−0.71 (0.98)	−0.03	0.469
Education	–	–	–	0.10 (0.45)	0.01	0.820	−0.44 (0.41)	−0.06	0.280	−0.49 (0.35)	−0.07	0.164
Income	–	–	–	0.64 (0.27)	0.14	**0.020**	0.46 (0.24)	0.10	0.061	0.31 (0.21)	0.07	0.144
Alcohol use	–	–	–	–	–	–	0.86 (0.55)	0.08	0.117	−0.01 (0.48)	−0.00	0.985
Smoking status	–	–	–	–	–	–	−3.36 (1.02)	−0.19	**0.001**	−3.56 (0.88)	−0.20	**<0.001**
Sleep disturbance	–	–	–	–	–	–	−0.49 (0.06)	−0.42	**<0.001**	−0.34 (0.05)	−0.29	**<0.001**
LC intensity	–	–	–	–	–	–	–	–	–	−0.01 (0.00)	−0.48	**<0.001**
Overall Adjusted R^2	0.12			0.14			0.34			0.51		
Overall model *p*-value	<0.001			<0.001			<0.001			<0.001		

[a]LC, long COVID; B, unstandardized coefficient; SE, standard error; *β*, standardized coefficient.
[b]Physical health assessed through the PROMIS Global Health v1.2 scale.
[c]Sleep was measured by the PROMIS Sleep Disturbance Short Form 4a.
[d]Alcohol consumption categorized as determined by the Dietary Guidelines for Americans, 2020–2025.
[e]Physical activity reported via self-report of moderate or vigorous physical activity (inactive = 0 min; insufficiently active = 1 to < 150 min, active = 150 to < 300 min, highly active = ≥ 300 min).
[f]LC intensity refers to the summed intensity of CDC-defined long COVID symptoms endorsed by participants, with endorsed symptoms rated on a 0–100 scale.
[g]Variables coded as detailed in Table 1.
[h]Bolded results significantly contributed to the model.

$t(281) = -0.90$, $p = 0.369$). Detailed regression results can be found in Table 3.

Post-hoc comparison tests with Bonferroni adjustment (Model 3) were utilized to determine estimated marginal means of perceived physical health *T*-score by PA level, M(SE): inactive: 36.1 (0.9); insufficiently active: 39.7 (0.5); active: 42.8 (0.8); highly active: 41.1 (1.8). The comparison tests with Bonferonni adjustment demonstrated that the inactive group reported significantly worse perceived physical health than the insufficiently active ($p = 0.002$) and active ($p < 0.001$) groups. The insufficiently active group had significantly worse perceived physical health than the active group ($p = 0.013$). The highly active group did not significantly differ from any of the other PA levels (*p*s > 0.05), in part due to small sample size. *Post-hoc* comparison tests with Bonferroni adjustment (Model 3) were utilized to determine estimated marginal means of perceived mental health *T*-score by PA level, M(SE): inactive: 38.1 (0.9); insufficiently active: 41.6 (0.6); active: 43.0 (0.9); highly active: 42.0 (1.9). The comparison tests with Bonferonni adjustment showed the inactive group had significantly worse perceived mental health than the insufficiently active ($p = 0.009$) and active ($p < 0.001$) groups. The highly active group did not significantly differ in their mental health from any other activity group ($p > 0.05$). Figure 1 demonstrates these relationships among PA levels.

Combined symptom intensity, considering all CDC-defined long COVID symptoms, was significantly higher among inactive individuals. The inactive group reported significantly greater combined long COVID intensity compared to the insufficiently active ($p < 0.001$), active ($p < 0.001$), and highly active ($p = 0.006$) groups following Bonferroni adjustment. However, no other comparisons among PA levels were significant (*p*s > 0.05). Overall intensity ratings by PA level can be viewed in Figure 2. The average intensity within each CDC-defined symptom category generally showed the highest intensity rating across symptom categories among the inactive group, except for the digestive symptom category, which had the highest intensity rating among the highly active group. However, the only

TABLE 3 Multivariable linear regression of PA level and long COVID symptom intensity on mental health.

	Model 1			Model 2			Model 3			Model 4		
	B (SE)	*β*	*p*-value	*B* (SE)	*β*	*p*-value	*B* (SE)	*β*	*p*-value	*B* (SE)	*β*	*p*-value
PA level	2.92 (0.59)	0.28	**<0.001**	2.57 (0.56)	0.25	**<0.001**	2.00 (0.53)	0.19	**<0.001**	0.89 (0.49)	0.09	0.067
Age (years)	–	–	–	0.11 (0.03)	0.23	**<0.001**	0.09 (0.03)	0.17	**0.006**	0.10 (0.03)	0.19	**<0.001**
Gender identity	–	–	–	−2.87 (0.91)	−0.17	**0.002**	−2.50 (0.88)	−0.15	**0.005**	−0.86 (0.80)	−0.05	0.287
Racial group	–	–	–	−0.02 (1.33)	−0.00	0.986	0.16 (1.24)	0.01	0.899	0.09 (1.09)	0.00	0.934
Ethnic group	–	–	–	−1.60 (1.28)	−0.07	0.215	−1.39 (1.20)	−0.06	0.246	−1.44 (1.06)	−0.06	0.175
Education	–	–	–	−0.30 (0.45)	−0.04	0.511	−0.62 (0.42)	−0.08	0.144	−0.67 (0.38)	−0.09	0.077
Income	–	–	–	0.64 (0.27)	0.14	**0.018**	0.57 (0.26)	0.13	**0.027**	0.42 (0.23)	0.09	0.063
Alcohol use	–	–	–	–	–	–	1.16 (0.58)	0.10	**0.044**	0.33 (0.52)	0.03	0.526
Smoking status	–	–	–	–	–	–	−0.60 (1.07)	−0.03	0.576	−0.79 (0.95)	−0.05	0.402
Sleep disturbance	–	–	–	–	–	–	−0.39 (0.06)	−0.33	**<0.001**	−0.25 (0.06)	−0.21	**<0.001**
LC intensity	–	–	–	–	–	–	–	–	–	−0.01 (0.00)	−0.45	**<0.001**
Overall Adjusted R^2	0.08			0.18			0.30			0.45		
Overall model *p*-value	<0.001			<0.001			<0.001			<0.001		

[a]LC, long COVID; B, unstandardized coefficient; *β*, standardized coefficient.
[b]Physical health assessed through the PROMIS Global Health v1.2 scale.
[c]Sleep was measured by the PROMIS Sleep Disturbance Short Form 4a.
[d]Alcohol consumption categorized as determined by the Dietary Guidelines for Americans, 2020–2025.
[e]Physical activity reported via self-report of moderate or vigorous physical activity (inactive = 0 min; insufficiently active = 1 to < 150 min, active = 150 to < 300 min, highly active = ≥ 300 min).
[f]LC intensity refers to the summed intensity of CDC-defined long COVID symptoms endorsed by participants, with endorsed symptoms rated on a 0–100 scale.
[g]Variables coded as detailed in Table 1.
[h]Bolded results significantly contributed to the model.

significant comparison among symptom groups by PA level was significantly greater general long COVID intensity among the active group compared to the inactive group ($p = 0.005$). Average intensity symptom ratings by symptom group and PA level can be viewed in Figure 2b.

Discussion

The significant association between PA level and perceived physical health among individuals with long COVID fits with literature noting improvements in physical health with increasing PA levels among both control and long COVID samples (Anderson and Durstine, 2019; Fugazzaro et al., 2022; Araújo et al., 2023). Similar to the PA and perceived physical health association, PA was significantly associated with perceived mental health among the sample, fitting with PA intervention studies in the context of long COVID (Araújo et al., 2023). Long COVID intensity was significantly associated with both perceived physical and mental health after accounting for sociodemographic and health behaviors, including PA level. PA level continued to be significantly associated with perceived physical health after accounting for long COVID intensity, further supporting the idea that PA appears to be uniquely associated with physical health in long COVID beyond sociodemographic, illness severity, and health behavior factors (Humphreys et al., 2021; Wright et al., 2022; Colas et al., 2023).

Increasing PA levels were generally associated with increasing levels of perceived health, fitting with literature noting better physical and mental health ratings among individuals with long COVID engaging in more PA (Vélez-Santamaría et al., 2023). Comparisons involving the inactive category particularly stood out, with insufficiently active and active groups reporting significantly greater perceived physical and mental health scores than inactive individuals. These results suggest that any amount of PA within the comfort zone

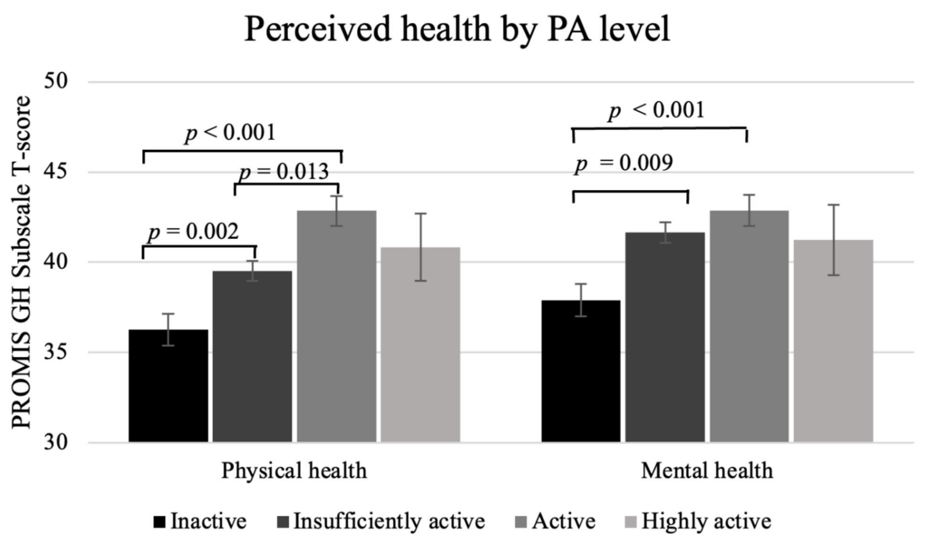

FIGURE 1
Perceived physical and mental health by PA level among individuals with long COVID. Physical health assessed through the PROMIS Global Health v1.2 scale. Physical activity reported via self-report of moderate or vigorous physical activity (inactive = 0 min; insufficiently active = 1 to <150 min, active = 150 to <300 min, highly active = ≥300 min). Estimated marginal means shown, adjusted for age, gender identity, racial and ethnic group, education, income, alcohol consumption, current smoking status, and sleep disturbance. Standard error bars shown.

and ability level of individuals with long COVID may provide physical and mental health benefits, although prospective data are required. The consistent increases in perceived physical and mental health with increasing PA level fits with established literature in both healthy and clinical samples demonstrating that even a small volume of PA can have measurable health benefits (Blair et al., 1992; Huber et al., 2020; Centers for Disease Control and Prevention, 2023b).

Although the insufficiently active and active groups reported better perceived physical and mental health than inactive individuals, comparisons of other PA levels with the highly active group were not significant in both perceived physical and mental health analyses, conflicting with findings in the general population showing that each increased activity level is associated with better perceived health (Tyson et al., 2010). It is unclear why there was a tapering of perceived health observed among the highly active group, but there are several possible explanations. Post-exertional malaise, or worsened symptoms following physical, mental, or emotional exertion, can affect both physical and mental health and it has been noted following PA among individuals with long COVID (Stussman et al., 2020; Humphreys et al., 2021; Vernon et al., 2023; Appelman et al., 2024). It is possible that high levels of PA, while providing some perceivable health benefits, may also be associated with post-exertional malaise, attenuating perceived health. However, post-exertional malaise is often noted following even low intensity and duration of exertion among individuals affected (Centers for Disease Control and Prevention, 2023a), and it is unclear whether or why individuals reporting high levels of activity may be particularly prone in this sample. Symptomatic responses to PA were also not assessed in our sample, complicating the consideration of response to exercise and post-exertional malaise among PA groups.

Regarding the lack of significant perceived mental health comparisons among the highly active group, individuals who were physically active before COVID-19, such as living an active lifestyle or being a competitive athlete, have reported significant losses of identity associated with long COVID development and loss of abilities (Humphreys et al., 2021; Shelley et al., 2021; Wurz et al., 2022). It is possible that individuals who were physically active before COVID-19 may continue to attempt high levels of PA, becoming frustrated when their physical ability limitations become apparent (Humphreys et al., 2021; Shelley et al., 2021; Wurz et al., 2022), leading to the lack of improved perceived mental health noted among highly active individuals with long COVID. Observational studies among long COVID samples have reported conflicting associations between PA and mental health, with some participants reporting improved mental health and cognitive functioning with PA, while others report that their symptoms worsen (Humphreys et al., 2021; Shelley et al., 2021; Wright et al., 2022). Illness perception, coping mechanisms, and previous mental health status may each affect how an individual understands and manages their condition, affecting their mental health, thus offering other explanations for the results that were not accounted for in the regression analyses (Turner and Kelly, 2000; Petrie et al., 2008; Algorani and Gupta, 2023). The relatively low number of individuals with long COVID reporting being highly active ($N = 26$; 6.9%) compared to the other PA level groups is another important consideration. The highly active group reported greater variation in perceived health compared to the other PA levels, with over double the standard error of the second most variable PA level in both the physical health (SE = 1.83), and mental health (SE = 1.96) models. Therefore, it appears that individuals reporting both relatively low and high ratings of perceived health (physical health range: $T = 26.7–54.1$; mental health range: $T = 28.4–62.5$) may have been included in this PA level group, creating a wide distribution of perceived health scores within the highly active group and contributing to the lack of significant comparisons observed.

Long COVID severity is another important consideration in understanding perceived health. Individuals with severe ME/CFS are often bedbound for extensive periods of time, limiting most PA including activities of daily living (Chang et al., 2021; Montoya et al.,

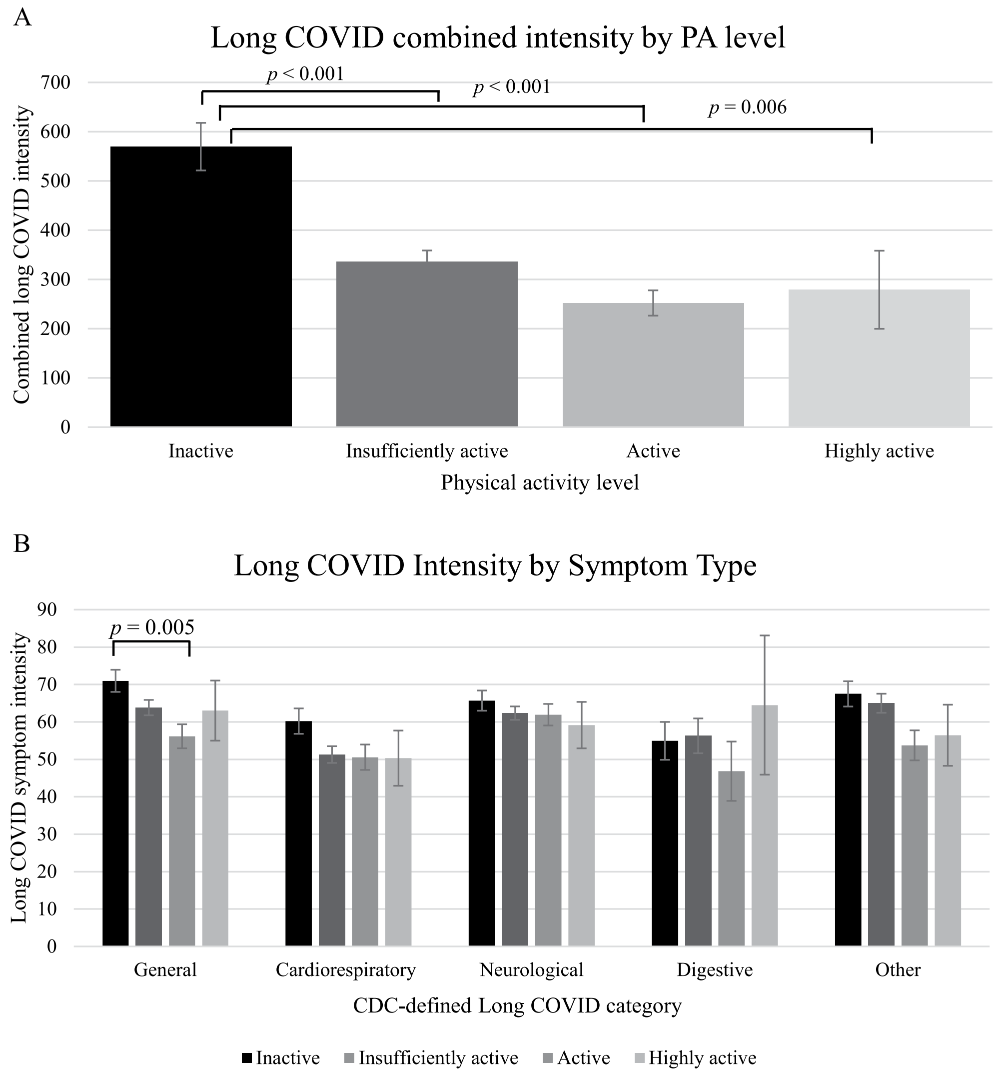

FIGURE 2
(a) Long COVID combined intensity by PA level. (b) Long COVID intensity in each CDC-defined symptom group by PA level. Mean intensity shown. Physical activity reported via self-report of moderate or vigorous physical activity (inactive = 0 min; insufficiently active = 1 to <150 min, active = 150 to <300 min, highly active = ≥ 300 min). Long COVID symptom groups are as defined by the CDC. All comparisons not noted as significant had *p*-values >0.05 following Bonferroni adjustment. Standard error bars shown.

2021). Long COVID appears to follow a similar course, with severely affected individuals limited in most aspects of daily life (Brodin et al., 2022; Davis et al., 2023). Severely ill individuals with ME/CFS have noted significant health burden (Chang et al., 2021; Ziauddeen et al., 2022), including fatigue, pain interference, and pain behavior. Given the strong associations between ME/CFS and long COVID (Komaroff and Lipkin, 2023), it seems plausible that long COVID severity may be driving the association noted between PA levels and perceived physical and mental health (i.e., people with severe symptoms may be more likely to be inactive and have worse perceived health). Following the addition of combined long COVID severity to the model, however, current PA level remained significantly associated with perceived physical health ($p < 0.001$), but not perceived mental health ($p = 0.067$). The few significant differences among PA groups in average severity by CDC-defined symptom category further suggest that PA appears to be uniquely associated with perceived physical health, suggesting that PA promotion, even to levels below the current PA guidelines, may be helpful in enhancing physical health in the context of long COVID.

Although PA level continued to be associated with perceived physical health after accounting for long COVID intensity, long COVID intensity was a stronger predictor of perceived health. Long COVID intensity had an absolute standardized coefficient more than three times greater than that of PA in predicting perceived physical health ($\beta = -0.48$ and 0.15, respectively), and an absolute standardized coefficient more than four times greater than that of PA in predicting mental health ($\beta = -0.45$ and 0.09, respectively). This result seems to fit with literature noting that perceived severity of illness is negatively associated with perceived health in clinical contexts (Lackner et al., 2014; Kim et al., 2015). Therefore, while PA level appears to be positively associated with perceived physical and mental health, the intensity of long COVID symptoms experienced appears to be a more impactful predictor. Increasing PA levels, particularly from inactive to at least some PA may be a useful long COVID management technique, however, our results indicate that targeting long COVID intensity, and ensuring that PA does not worsen symptoms, must be considered as well. Strategies previously suggested in the context of other somatic syndromes include treating the most disruptive symptoms first and identifying treatment strategies that target multiple symptoms for maximum benefit (Centers for Disease Control and Prevention, 2021).

This study had limitations. First, the survey offered a cross-sectional assessment of long COVID and PA, as well as perceived physical and mental health, and causation and direction of association cannot be inferred. The survey relied on participant self-report for diagnosis of COVID-19, though it has been reported that some who report prior COVID-19 infection do not have COVID-19 antibodies (Matta et al., 2022). PA status was also self-reported, and muscle strengthening PA was not assessed. Moderate and vigorous intensity PA were not individually assessed, and the PA level assignment of individuals may vary from the 2018 Physical Activity Guidelines for Americans, which doubles vigorous minutes in the determination of moderate-to-vigorous PA level (U.S. Department of Health and Human Services, 2018). In addition, limited medical history was obtained, and it is unclear how unmeasured physical comorbidities might have affected the results. The inclusion and exclusion criteria, as well as the recruitment strategies utilized in the study may have affected those who participated in the study, limiting generalizations and conclusions that can be drawn from the data. Although this study consisted of largely of individuals with white and not Hispanic or Latino identities, as well as those with high educational attainment and higher annual income, individuals with not white and Hispanic or Latino identities, as well as individuals with lower educational attainment and lower annual income have been suggested to be more likely to develop long COVID and be more severely affected (Wong and Weitzer, 2021; Jacobs et al., 2023; Tanne, 2023). No official definition of long COVID was utilized, with all participants endorsing current long-term symptoms following COVID-19 being considered to have long COVID. However, the prevalence of long COVID in our overall sample was 8.8%, which is smaller than the estimated 10–20% for individuals with COVID-19 infection developing long COVID in the general population (The Lancet, 2023). Therefore, our sample is likely more conservative in identifying those with long COVID. Not all CDC-defined long COVID symptom categories were noted by each individual reporting long COVID, leaving smaller sample sizes in several symptom categories. Finally, while participants were asked about long COVID intensity, frequency and duration of long COVID symptoms were not probed though these factors may also affect perceived long COVID severity.

Conclusion

PA level was significantly positively associated with both perceived physical and mental health among individuals with long COVID. PA remained associated with perceived physical health even after accounting for the intensity of long COVID symptoms. Individuals reporting insufficiently active or active PA levels each reported significantly better perceived physical and mental health than individuals who reporting inactive PA levels, suggesting that even modest amounts of PA may be associated with significantly better perceived health among individuals with long COVID. However, long COVID symptom intensity appears to be a stronger predictor of perceived physical and mental health than PA, emphasizing the importance of targeting disruptive symptoms in addressing long COVID. This study was cross-sectional, and future PA intervention studies and dose–response studies may be helpful in further elucidating the relationship between PA level and perceived health among individuals with long COVID. In addition, future studies could assess the impact of changing PA level on specific physical and mental health outcomes, such as functional ability level, pain, or clinical depression and anxiety.

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 Iowa State University Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin because participants noted consent when clicking to the next screen of a survey. As the survey was anonymous and personally identifying information was not shared, the Iowa State University Institutional Review Board approved this protocol for obtaining participant consent.

Author contributions

ZS: Conceptualization, Formal analysis, Methodology, Writing – original draft. DL: Methodology, Writing – review & editing. AB: Conceptualization, Formal analysis, Investigation, Methodology, 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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Causal relationships among perception of errors, challenges, and deliberate practice in athletes with disabilities

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Introduction: There is limited evidence that the psychological characteristics of athletes with disabilities are identical to those of non-disabled athletes, owing to differences in ecological traits, and there is insufficient information on how athletes with disabilities perceive disabled athletes' perception of errors, challenges, and deliberate practice. Therefore, it is necessary to examine whether the causal model of the perception of errors, challenge, and deliberate practice will be reproduced in the same way as in non-disabled athletes. Therefore, this study aimed to verify a causal model of the perception of errors, challenges, and deliberate practice by athletes with disabilities.

Methods: The participants were 189 athletes with physical and hearing impairments (131 men and 58 women) registered with the 2023 Korea Paralympic Committee. Data were collected through a survey and the participants responded using a self-report method. The collected data were analyzed using descriptive statistics to verify normality, correlation analysis to examine relationships between variables, and structural equation modeling (SEM) to test the hypotheses.

Results: Based on SEM analysis, the results of this study showed that the causal relationships between the perception of errors, challenges, and deliberate practice were partially significant. Specifically, perception of errors and reflection positively predicted challenges, whereas burden of mistakes negatively predicted challenges. Additionally, challenges were found to have a positive effect on deliberate practice.

Discussion: By comprehensively examining the above, it can be interpreted as a major factor that can promote and reduce challenges depending on how athletes with disabilities perceive their mistakes.

KEYWORDS

psychological conditioning, Taekwondo athlete, physical disability, hearing disability, structural equation model

1 Introduction

Errors experienced by athletes during training and competitions consistently occur as athletes attempt to reach their personal goals (Keith and Frese, 2008). Individual athletes perceive errors differently, which can affect their emotions and cognitive behaviors (Schell and Conte, 2008). As there is a close correlation between error recognition and athletic performance, these issues must be examined from various perspectives. The results of numerous studies on perception of error using multiple approaches have shown that perception of error has positive effects on athletic performance, along with numerous other factors. Lee et al. (2021) reported that those with a higher level of achievement goals tended to perceive errors more positively and take challenging approaches. Additionally, Sim et al. (2022) showed that a higher level of achievement goals positively affects the perception of errors and grit.

Research indicates that the perception of errors positively influences key psychological factors such as self-confidence, self-regulation, performance, grit, achievement goals, and perfectionism (Apró et al., 2024). These findings highlight the significance of adopting a constructive approach toward mistakes (Malureanu et al., 2021). Moreover, a positive perception of errors has been identified as a critical factor that enhances task-oriented goal pursuit and fosters the acquisition of new skills or solving complex problems, closely linking it to increased motivation (Farr et al., 1993). From a cognitive-behavioral perspective, focusing on errors shifts attention from outcome-based evaluations to a process-oriented mindset, providing individuals with opportunities for growth rather than withdrawal in the face of challenges. Previous research has predominantly aimed to predict variations in certain psychological constructs based on the perception of error. Challenges emerged as variables that may be significantly influenced by how individuals perceive mistakes.

Meanwhile, challenge refers to an individual's disposition toward the perception of new and difficult tasks, which increases task performance and concentration (Hektner, 1997). It can also be defined as the positive desire to achieve personal goals (Csikszentmihalyi, 2011). This challenge was first introduced by the flow theory and is presented as a crucial factor that increases personal competence and athletic performance (Csikszentmihalyi, 2011). The conceptual trait of challenge plays an essential role in boosting athletes' potential by triggering positive emotions and encouraging them to examine their weaknesses and train accordingly (Csikszentmihalyi, 2011). Challenge, in particular, has been shown to be closely associated with competitiveness, interest, effort, and practice (Sim et al., 2022). Previous studies on challenges have consistently suggested that they play a key role in explaining various traits related to personal achievement and success. Given its conceptual nature, challenge induces positive emotions and encourages individuals to reflect on their weaknesses and progressively improve, making it a critical factor in unlocking athletic potential (Csikszentmihalyi, 2011). As a result, a sense of challenge enhances deliberate practice.

Deliberate practice refers to the strategic and systematic behavior of individuals who understand their weaknesses, establish organized plans, and make endless efforts (Ericsson, 2009). It is a major determinant of athletes' abilities because it is a critical element of professionalism and allows athletes to set advanced goals and take progressive measures even when encountering difficulties (Verner-Filion et al., 2017). As athletes need to use proper skills at the right time when performing competitions, setting persistent goals and maintaining professionalism through deliberate practice play critical roles.

Deliberative practices are closely associated with individuals' motivations and attitudes. Duckworth et al. (2011) showed that deliberate practice compensates for athletes' weaknesses and maximizes their strengths. As there are different perspectives on interpreting errors, the perception of errors reportedly affects one's deliberate practice (Ford et al., 2009). In other words, to maintain self-directed deliberate practice, positive perception of errors and risk-taking attitudes are critical. Previous research on deliberate practice has focused on variables such as goal commitment, grit, satisfaction, self-regulation motivation, passion, and behavioral change, suggesting a close relationship between deliberate practice and individual motivation and attitude. Duckworth, Kirby, Tsukayama, Berstein, and Ericsson (Ericsson, 2009) posited that deliberate practice serves as a mechanism for athletes to compensate for their weaknesses and maximize their strengths. They also found that how athletes interpret mistakes influences deliberate practice, with the acceptance of mistakes playing a key role in this process (Fiori and Zuccheri, 2005; Ford et al., 2009). In other words, a positive perception of mistakes and a challenging attitude are crucial for sustaining self-directed deliberate practices.

Considering the points presented above, it can be predicted that error perception functions as a motivational factor for athletes, enhancing their sense of challenge, which, in turn, affects deliberate practice. However, error perception is a relatively recent motivational variable and its accumulation in subsequent research is limited. Although much research has been conducted in the field of education, its interpretation in the field of sports science is still ongoing. Additionally, most studies on deliberate practice have focused on elite athletes (Vink et al., 2015; Macnamara et al., 2016; Ericsson, 2020), but the accumulated evidence on consistent antecedent variables that explain deliberate practice remains limited.

Therefore, this study aimed to model the relationship between error perception and challenge as antecedent variables that can enhance deliberate practice in athletes, and examine the psychological characteristics that can improve athletic performance.

This study developed a model that could be applied to athletes with disabilities. There is limited evidence that the psychological characteristics of athletes with disabilities are the same as those of athletes without disabilities because of physiological differences (Sherrill, 1998). Therefore, little is known about the perception of errors, challenges, and deliberate practice of athletes with disabilities. Moreover, whether the causal model of the perception of errors, challenges, and deliberate practice can be applied to athletes with disabilities in the same way as those without disabilities needs to be evaluated. Hence, this study aimed to validate a causal model of the perception of errors, challenges, and deliberate practices in athletes with disabilities. Referring to the aforementioned studies, we developed the following hypothesis: Learning from errors, challenges, and the burden of mistakes will affect challenges. The perception of errors will affect challenges, which in turn will affect deliberate practice. A challenge will be a mediator between reflection of errors and deliberate practice.

2 Materials and methods

2.1 Participants

This study complied with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) checklist, and the study protocol was approved by the Institutional Review Board at

Wonkwang University, and was performed in compliance with the Helsinki Declaration and ethical research principles (WKIRB-202211-SB-111). The participants of this study were elite athletes with physical and hearing abilities registered with the 2023 Korea Paralympic Committee. The sample size of our study participants was calculated using G-power 3.1 (University of Kiel, Kiel, Germany). The estimated sample size was determined through an F-test for linear multiple regression, with [effect size: 0.15 (default), significance level: 0.05, power: 0.95], resulting in a total of 130 participants. Considering missing data, we recruited 207 participants. The purpose of the study was fully explained to the directors and authorities of the committee prior to the study, and 207 samples were collected through convenience sampling. A total of 189 participants were included in the final analysis after excluding 18 participants based on the following criteria: inconsistent responses across similar items, incomplete surveys with missing data, extreme or outlier values, non-random response patterns (e.g., selecting the same option throughout), and surveys completed in an unreasonably short or excessively long amount of time, indicating either a lack of attention or difficulty in understanding the questions. The exclusion criteria ensured the reliability and quality of the data used in the analysis. The sociodemographic characteristics of the participants are presented in Table 1.

2.2 Study instrument

To meet the aims of this research, the instrument used in this study was revised and adapted from a structured questionnaire used in previous studies. Particular attention was given to ensure that the items used in previous research could also be appropriately applied to athletes with disabilities and in the field of adaptive sports. To verify this, content validity was assessed by three experts in the field of adaptive sports (one professor of adapted physical education, one PhD in adapted physical education, and one coach specializing in disability sports), and all items were deemed acceptable for use. The questionnaire consisted of 34 questions: 4 items on sociodemographic characteristics, 17 items on perception of errors, 6 items on deliberate practice, and 7 items on challenge. The questionnaire content is presented in Table 2.

TABLE 1 Characteristics of the participants.

Demographics	Category	Number of participants	N (%)
Gender	Male	131	69.3
	Female	58	30.6
Age	<20 years	48	25.4
	<30 years	77	40.7
	≥30 years	64	33.9
Career	Less than 2 years	37	19.6
	Less than 4 years	98	51.9
	Less than 4 years	27	15.8
	6 years or more	24	12.7
National competition award	Yes	112	59.3
	No	77	40.7
Total		189	100

To examine the construct validity of the survey tool, confirmatory factor analysis (CFA) using the Maximum Likelihood (ML) estimation method and reliability analysis using Cronbach's α were conducted. The model fit criteria were interpreted as follows: TLI and CFI values below 0.90, and SRMR and RMSEA values below 0.08 which considered to indicate good fit (Kline, 2023). Additionally, to assess convergent validity, the average variance extracted (AVE) and construct reliability (CR) were measured, with AVE values above 0.50 and CR values above 0.70 interpreted as indicating good fit (Fornell and Larcker, 1981; Anderson and Gerbing, 1988).

2.2.1 Perception of errors

To measure the perception of errors, the Error Orientation Questionnaire (EOQ) developed by Rybowiak et al. (1999) and validated by Sim and Seo (2022) for Korean athletes was used. The adapted questionnaire consisted of 17 questions in four categories: 4 items for learning from errors, 4 items for challenging errors, 4 items for the burden of mistakes, and 5 items for reflecting on errors. The 5-point Likert Scale was used to analyze the responses.

2.2.2 Challenge

To measure challenge, Student perceptions of classroom quality (SPOCQ), developed by Gentry and Owen (2004), translated by Lee and Choi (2016), and validated by Sim and Seo (2021) for Korean athletes were used in this study. The questionnaire consisted of six questions in a single category and a 5-point Likert Scale was used to analyze the responses.

2.2.3 Deliberate practice

To measure deliberate practice, this study used a questionnaire developed by Vallerand et al. (2008), translated by Yang (2015), and validated by Sim and Seo (2020) for Korean athletes. The questionnaire consisted of five questions in a single category, and a 4-point Likert Scale was used to analyze the responses.

2.2.4 Validity and reliability of the study instrument

To test the validity of the items in the aforementioned study instruments before their application, a team of experts (a professor of special physical education, an expert with a PhD in special physical education, and a sports manager working with disabled athletes) validated the questionnaires. Furthermore, to verify the evidence for construct validity, a confirmatory factor analysis (CFA) based on maximum likelihood (ML) estimation and reliability analysis using Cronbach's α was performed. Here, the standards for the goodness of fit of the model were set as TLI and CFA ≤0.90, and the SRMR and RMSEA ≤0.80 (Kline, 2023). To examine convergent validity, average variance extracted (AVE) and construct reliability (CR) were measured. The standards for AVE was ≥0.50 and CR was ≥0.70 for good fit (Fornell and Larcker, 1981; Anderson and Gerbing, 1988).

2.2.5 Confirmatory factor analysis and reliability of perception of errors

Confirmatory analysis of perception of errors showed a fitness of $\chi^2 = 177$, df = 113, TLI = 0.958, CFI = 0.966, SRMR = 0.052, and RMSEA = 0.054. The reliability was 0.916 for learning from errors, 0.928 for challenging errors, 0.843 for the burden of mistakes, and 0.891 for

TABLE 2 Survey contents.

Categories	Contents	Items
Sociodemographic characteristics	Gender, age, experience, types of sports	4
Perception of errors	Learning from errors	4
	Challenging errors	4
	Burden of mistakes	4
	Reflection of errors	5
Challenge		7
Deliberate practice		6
Total		34

the reflection of errors (Table 3). Hence, the scale for perception of errors used in this study satisfied the evidence of construct validity.

2.2.6 Confirmatory factor analysis and reliability of challenge

Confirmatory analysis of challenge showed the fitness of $\chi^2 = 13.3$, df = 9, TLI = 0.991, CFI = 0.995, SRMR = 0.015, and RMSEA = 0.050. Reliability was 0.923 for challenge (Table 3). Hence, the scale for challenge used in this study provides evidence of construct validity.

2.2.7 Confirmatory factor analysis and reliability of deliberate practice

Confirmatory analysis of challenge showed the fitness of $\chi^2 = 12.3$, df = 5, TLI = 0.960, CFI = 0.980, SRMR = 0.028, and RMSEA = 0.077.

TABLE 3 Confirmatory factor analysis and reliability analysis of perception of errors, challenge, deliberate practice.

Latent variable		Variable	*B*	*β*	S.E	*t*	AVE	C.R	*α*
Perception of errors	Learning from errors	a1	0.777	0.851	0.054	14.28***	0.930	0.981	0.916
		a2	0.791	0.878	0.052	15.00***			
		a3	0.872	0.896	0.056	15.51***			
		a4	0.779	0.803	0.059	13.03***			
	Challenging errors	a5	0.567	0.664	0.059	9.55***	0.895	0.971	0.829
		a6	0.785	0.77	0.067	11.67***			
		a7	0.734	0.76	0.063	11.48***			
		a8	0.826	0.779	0.069	11.87***			
	Burden of mistakes	a9	0.730	0.694	0.07	10.40***	0.898	0.972	0.843
		a10	0.989	0.916	0.065	15.20***			
		a11	0.814	0.779	0.067	12.07***			
		a12	0.601	0.645	0.063	9.46***			
	Reflection of errors	a13	0.587	0.712	0.054	10.86***	0.921	0.983	0.891
		a14	0.688	0.852	0.048	14.08***			
		a15	0.641	0.756	0.054	11.82***			
		a16	0.713	0.836	0.052	13.70***			
		a17	0.714	0.788	0.057	12.49***			
$\chi^2 = 177$, df = 113, TLI = 0.958, CFI = 0.966, SRMR = 0.052, RMSEA = 0.054									
Challenge		b1	0.752	0.833	0.054	12.9***	0.925	0.987	0.923
		b2	0.794	0.872	0.053	15.5***			
		b3	0.780	0.887	0.05	12.5***			
		b4	0.688	0.787	0.054	14.5***			
		b5	0.761	0.833	0.054	10.7***			
		b6	0.618	0.691	0.058	10.7***			
$\chi^2 = 13.3$, df = 9, TLI = 0.991, CFI = 0.995, SRMR = 0.015, RMSEA = 0.050									
Deliberate practice		c1	0.490	0.612	0.056	8.70***	0.905	0.979	0.844
		c2	0.609	0.728	0.055	10.92***			
		c3	0.614	0.76	0.052	11.65***			
		c4	0.757	0.867	0.054	13.98***			
		c5	0.523	0.629	0.058	9.02***			
$\chi^2 = 12.3$, df = 5, TLI = 0.960, CFI = 0.980, SRMR = 0.028, RMSEA = 0.077									

***$p < 0.001$.

Reliability was 0.844 for deliberate practice (Table 3). Hence, the scale for deliberate practice used in this study demonstrated construct validity.

2.3 Procedure

Data were collected via face-to-face surveys. The researchers contacted the representatives or team officials of the athletes' organizations in advance to recruit participants. Visits were scheduled only for teams that agreed to cooperate and provided approval for the study. The research team then visited the teams according to their schedules. Participants were provided with detailed explanations of the study's purpose, methods, and ethical considerations. It was emphasized that participation should not be influenced by coercion from coaches or team officials and that there would be no disadvantages for those who chose not to participate. For teams that included athletes with hearing disabilities, information was conveyed through sign language with the assistance of a specialist. Subsequently, the participants signed consent forms, and the surveys were distributed. The participants completed the surveys using a self-report method and the completed surveys were collected immediately. The collected surveys underwent coding and data cleaning, and were then analyzed according to the study's purpose and methods.

2.4 Data analysis

Processing of data collected from this study were performed using Jamovi 2.0 (IBM, New York, USA) and AMOS 23.0 (IBM, New York, USA) to validate the hypothesis. Significance level (α) was set as 0.05. A detailed analysis is provided below.

A frequency analysis was conducted for sociodemographic characteristics. Confirmatory factor analysis (CFA) based on maximum likelihood (ML) estimation and reliability analysis were conducted to verify the evidence for construct validity. In addition, skewness and kurtosis were analyzed to test normality, and Pearson's R correlation analysis were performed to examine the relationships between major variables. Finally, prior to validating the study model, the goodness of fit for measurement models proposed by Anderson and Gerbing (1988) was reviewed, and the structural model was analyzed.

3 Results

3.1 Normality test

As the estimation of the measurement and structural models was based on maximum likelihood (ML) in this study, normality was tested, which is its underlying assumption. The results showed the skewness of −0.424 ~ 0.389 and kurtosis of −0.612 ~ 0.543 as shown in Table 4, which met the standards proposed by Kline (2023) (skewness ≤ ±3, kurtosis ≤ ±8).

3.2 Correlation analysis

Pearson's R correlation analysis was conducted to examine the relationships among the perception of errors, challenges, and deliberate practice. As shown in Table 5, the sub-variables of the three variables (perception of errors, challenges, and deliberate practice) had partial correlations. All coefficients were ≤ 0.80, which is the standard of multicollinearity, indicating that the concepts of the three variables (perception of errors, challenge, and deliberate practice) did not overlap (Kline, 2023).

3.3 Validation of the measurement model

The measurement model was first validated before using the structural equation model (SEM) according to Anderson and Gerbing (1988). The pathway for validating the SEM was saturated, and the goodness-of-fit of the measurement model was tested. The result demonstrated that the goodness of fit described by $\chi^2 = 545.528$, df = 0.339, TLI = 0.930, CFI = 0.938, SRMR = 0.075, and RMSEA = 0.057 met the standards (Kline, 2023). Moreover, the standardized coefficients (β) of each latent variables explaining measurement variables were 0.648 ~ 908 for perception of errors, 0.691 ~ 829 for challenge, and 0.605 ~ 851 for deliberate practice. As this validated the explanatory power of the measurement variables, SEM was analyzed. The details of measurement model validation are shown below (Table 6).

3.4 Validation of the structural model

To statistically determine whether the hypothesis was accepted or rejected. The perception of errors of elite athletes with disabilities

TABLE 4 Normality test.

		Skewness		Kurtosis	
		S	SEM	S	SEM
Perception of errors	Learning	−0.424	0.177	0.543	0.352
	Challenge	−0.003		−0.612	
	Strain	−0.244		0.096	
	Reflection	0.389		−0.464	
Challenge		−0.227		−0.15	
Deliberate practice		0.254		−0.242	

TABLE 5 Pearson's r correlation analysis of perception of errors, challenge, and deliberate practice.

	1	2	3	4	5	6
Learning from errors	1					
Challenging errors	0.570**	1				
Burden of mistakes	0.085	0.019	1			
Reflection of errors	0.397**	0.412**	0.375**	1		
Challenge	0.408**	0.471**	−0.083	0.390**	1	
Deliberate practice	0.362**	0.388**	0.077	0.574**	0.633**	1

**$p < 0.01$.

TABLE 6 Measurement model validation.

Latent variables	Measurement variables	B	β	t
Learning from errors	a1	1	0.853	Criterion variable
	a2	1.016	0.877	15.536***
	a3	1.121	0.895	16.074***
	a4	1.002	0.803	13.454***
Challenging errors	a5	1	0.661	Criterion variable
	a6	1.384	0.766	8.699***
	a7	1.317	0.77	8.726***
	a8	1.453	0.774	8.761***
Burden of mistakes	a9	1	0.648	Criterion variable
	a10	1.623	0.908	9.655***
	a11	1.361	0.786	8.999***
	a12	1.213	0.696	8.177***
Reflection of errors	a13	1	0.707	Criterion variable
	a14	1.177	0.849	10.843***
	a15	1.109	0.763	9.815***
	a16	1.224	0.837	10.702***
	a17	1.226	0.788	10.124***
Challenge	b1	1	0.829	Criterion variable
	b2	1.064	0.874	14.944***
	b3	1.041	0.887	15.313***
	b4	0.917	0.785	12.668***
	b5	1.016	0.833	13.851***
	b6	0.826	0.691	13.851***
Deliberate practice	c1	1	0.605	Criterion variable
	c2	1.203	0.696	7.596***
	c3	1.316	0.789	8.266***
	c4	1.534	0.851	8.625***
	c5	1.126	0.656	7.280***
$\chi^2 = 545.528$, df = 0.339, TLI = 0.930, CFI = 0.938, SRMR = 0.075, RMSEA = 0.057				

***$p < 0.001$.

(learning from errors, challenging errors, burden of mistakes, and reflection or errors) was set as an exogenous and independent variable, and challenge was set as an endogenous and mediating variable. Deliberate practices were used as the dependent variables. The goodness of fit of the model described by $\chi^2 = 545.528$, df = 0.339, TLI = 0.930, CFI = 0.938, SRMR = 0.075, and RMSEA = 0.057 met the standards proposed by Kline (2023) (Table 7). The details of hypothesis testing are presented below.

> *H1*: Learning from errors did not have a statistically significant effect on challenge.
>
> *H2*: Challenging errors had a positive (+) effect on challenge ($\beta = 0.244$, $t = 2.333$***).
>
> *H3*: Burden of mistakes had a negative (−) effect on challenge ($\beta = -0.291$, $t = -3.580$***).
>
> *H4*: Reflection of errors had a positive (+) effect on challenge ($\beta = 0.406$, $t = 4.275$***).
>
> *H5*: Challenge had a positive (+) effect on deliberate practice ($\beta = 0.727$, $t = 7.221$***).

The overall analysis of the results showed that challenging errors and reflection of errors, the sub-variables of perception of errors, had positive (+) effects on challenges, whereas the burden of mistakes had a negative (−) effect. When the perception of errors was controlled, challenge had a positive (+) effect on deliberate practice. In other words, an increase in challenging errors and reflection of errors leads to an increase in challenges, ultimately promoting deliberate practice. On the contrary, an increase in the burden of mistakes leads to a decrease in challenges, discouraging deliberate practice. Therefore, perception of errors (challenging errors, mistakes, and errors) can explain deliberate practice through the mediation of challenges.

To determine whether the effects of the pathways from these results were statistically significant, the indirect effects (mediating effects) of these variables were validated for statistical significance (Baron and Kenny, 1986). To test the indirect effect (mediating effect) between the perception of error (challenging errors, burden of mistakes, and reflection of errors) and deliberate practice, the bootstrap method was conducted with 2,000 replications, and statistical significance was determined at a bias-corrected 95% confidence interval (Shrout and Bolger, 2002). A detailed validation of the statistical significance of the mediating effects is presented in Table 8.

The mediating effect of challenge on the relationship between challenging errors and deliberate practice was not statistically significant. In the relationship between burden of mistakes and deliberate practice, the lower and upper bound values of challenge did not include '0,' which indicates a statistical significance of the mediating effect (Shrout and Bolger, 2002). This suggests that an increase in the burden of mistakes leads to a decrease in challenges, ultimately reducing deliberate practice. In the relationship between reflection of errors and deliberate practice, the lower and upper bound values of challenge did not include '0,' which indicates a statistical significance of the mediating effect (Shrout and Bolger, 2002). This suggests that an increase in reflection of errors leads to an increase in challenge and ultimately promotes deliberate practice, which supports hypothesis 4.

4 Discussion

This study aimed to elucidate the relationships among perception of errors, challenges, and deliberate practices among elite athletes with disabilities. The structural equation was analyzed using the sub-variables of perception of errors – learning from errors, challenging errors, burden of mistakes, and reflection of errors–as independent variables, challenge as a mediating variable, and deliberate practice as a dependent variable. A discussion of the results based on this setting is as follows.

The analysis of the effect of the perception of errors (learning from errors, challenging errors, burden of mistakes, and reflection of errors) on challenge showed that the perception of errors partially affected the challenge. The detailed results are discussed below.

TABLE 7 Goodness of fit of the model.

Latent variables			*B*	*β*	S.E	*t*	Hypothesis testing
Hypothesis 1	Learning from errors	Challenge	0.147	0.152	0.088	1.666	Reject
Hypothesis 2	Challenging errors		0.324	0.244	0.139	2.333***	Accept
Hypothesis 3	Burden of mistakes		−0.36	−0.291	0.101	−3.580***	Accept
Hypothesis 4	Reflection of errors		0.521	0.406	0.122	4.275***	Accept
Hypothesis 5	Challenge	Deliberate practice	0.471	0.727	0.065	7.221***	Accept
Goodness of fit: $\chi^2 = 545.528$, df = 0.339, TLI = 0.930, CFI = 0.938, SRMR = 0.075, RMSEA = 0.057							

***$p < 0.001$.

TABLE 8 Statistical significance of the mediating effect.

Latent variables			Lower bounds	Upper bounds	Indirect effects	*p*	Testing result
Challenging errors	Challenge	Deliberate practice	−0.008	0.367	0.172	0.063	Reject
Burden of mistakes	Challenge	Deliberate practice	−0.321	−0.084	−0.191	0.001	Accept
Reflection of errors	Challenge	Deliberate practice	0.121	0.471	0.276	0.001	Accept

***$p < 0.001$.

First, learning from errors did not have a statistically significant effect on challenge. This does not support the results of previous studies, which reported that various learning experiences enhance the behavior of challenge (Bird, 2004; Starbuck and Farjoun, 2005; Bauer, 2008; Roberts and Treasure, 2012). However, our results can be explained from the perspective of the decomposition of effects (Kline, 2023). Learning from errors refers to utilizing information obtained from errors. The fact that learning from errors did not affect challenge indicates that the roles of reflection and challenge rather than learning itself, have a greater effect on increasing challenges. In other words, the reflection of errors and challenging errors had strong effects on challenge among the total effect of the structural model, and it is likely that these effects were decomposed from the total effect. Correlation analysis showed a positive and statistically significant correlation between learning from errors and challenges. Therefore, learning from errors is likely to affect challenge. Roberts (Roberts and Treasure, 2012) reported that meeting the desire for challenge through continuous learning is crucial for improving athletic performance. Vaughan (Starbuck and Farjoun, 2005) showed that it also reduced negative patterns and slumps. These perspectives suggest that learning from errors enhances athletes' performance, underscoring the importance of a positive view on learning from errors. Providing stepwise goals to athletes with disabilities and reducing negative elements through regular counseling will be needed to establish positive psychological well-being in these athletes. Furthermore, efforts must be made to promote athletes' ability to learn from errors by monitoring videos of training or competitions and providing useful feedback and information.

Second, challenging errors were found to have a positive (+) effect on challenges. This result supports previous studies that reported the importance of risk-taking behavior in increasing the desire for challenges (Starbuck and Farjoun, 2005; Csikszentmihalyi, 2011; Lim and Yoon, 2017). Farr et al. (1993) suggest that cultivating a behavioral desire toward a challenge is important for decreasing the frequency of errors. Csikszentmihalyi (2011) proposed that an adventurous attitude toward personal growth acts as a mechanism that promotes challenges. In other words, challenging errors are a positive phenomenon that changes athletes' behavior and yields better outcomes.

The challenging attitude toward errors, characterized by behavioral tendencies, is reported to be critical for enhancing athletes' static skills, and their technique and concentration levels (Csikszentmihalyi, 2011; Dweck et al., 2014). Therefore, managers should encourage athletes' positive self-efficacy so that they do not fear error. Since self-efficacy is determined by the experience of success, verbal persuasion, and physical-psychological state (Kyun and EunChul, 2020), managers should explore various management strategies promoting behavioral characteristics of athletes with disabilities to enhance their self-efficacy and challenging attitude toward errors.

Third, the burden of mistakes has a negative (−) effect on challenges. This result supports numerous previous studies reporting that the fear of making errors reduces the desire for challenge (Bandura et al., 1999). Van Dyck et al. (2005) showed that the burden of mistakes leads to avoidance of challenges and negative emotions in athletes, which reduces their individual skills and performance. Hence, the burden of mistakes is likely to decrease athletes' motivational desire, hindering their performance capabilities (Keith and Frese, 2008; Schwebel et al., 2016). Managers must be aware that setting an atmosphere of overly focusing on winning can increase the burden of mistakes on athletes (Sherrill, 1998). They need to make efforts to emphasize the process and not the outcome to reduce the burden of mistakes. Furthermore, athletes with disabilities should develop positive emotions through a consistent reputation and image training to reduce the burden of mistakes.

Fourth, reflection of errors had a positive (+) effect on challenges. This result supports the theory that reflection on one's errors and a strong will to avoid repeating the same errors are critical in pursuing continuous challenges (Sherrill, 1998; Roberts and Treasure, 2012). Bauer (2008) proposed that boosting intrinsic motivation (e.g., challenge, achievement, and interest) is important for reflecting on errors and achieving one's goals. Reflection of errors can be strengthened by informational feedback, which is specific and useful information conveyed by managers to athletes about their errors (Sherrill, 1998). Hence, managers can improve athletes' challenges by providing consistent feedback through various strategies, such as recording training, logging performance, and providing peer review.

Our analysis of the effects of challenge on deliberate practice in elite athletes with disabilities showed that challenges positively (+) effect on deliberate practice. This supports previous findings that the desire for challenge promotes deliberate practice (Starkes and Ericsson, 2003; Yang, 2015). Starkes and Ericsson (2003) state that developing a positive desire for challenge is essential for facilitating continuous deliberate practice. This is consistent with Ericsson's study (Starkes and Ericsson, 2003), which proposed that challenges should precede systematic and strategic practice. Challenge is an essential desire of athletes to encourage professionalism and promote positive outcomes.

Validation of the mediating effect of challenge on the relationship between perception of errors and deliberate practice in elite athletes with disabilities showed that challenge did not have a statistically significant effect on the relationship between challenging errors and deliberate practice. However, challenge had a statistically significant mediating effect on the relationship between the burden of mistakes, reflection of errors, and deliberate practice. These results show that the burden of mistakes and reflection of errors explain deliberate practice through challenge; notably, taking into account the strongest effect of reflection of errors, athletes' willingness to actively reflect on their errors and avoid making the same errors will be most critical in promoting deliberate practice in athletes with disabilities (Starkes and Ericsson, 2003; Ericsson, 2009). Therefore, managers should make constant efforts to encourage athletes to reflect on their errors to enhance their deliberate practice. This will equip them with coaching strategies that can better manage the errors made by athletes with disabilities, which is a natural phenomenon that will ultimately improve their athletic performance.

5 Conclusion

This study elucidated the relationship among the perception of errors, challenges, and deliberate practices in athletes with disabilities. The results are as follows: First, learning from errors did not have a statistically significant effect on challenge. Second, challenging errors had a positive (+) effect on challenges. Third, the burden of mistakes has a negative (−) effect on challenges. Fourth, reflection of errors had a positive (+) effect on challenges. Fifth, challenge had a positive (+) effect on deliberate practice; finally, the mediating effect of challenge did not have a statistically significant effect on the relationship between challenging errors and deliberate practice. However, challenge had a negative (−) effect on the relationship between the burden of mistakes and deliberate practice and a positive (+) effect on the relationship between reflection of errors and deliberate practice with statistical significance.

Overall, the perception of errors in athletes with disabilities is a major factor that can facilitate or discourage challenges. In other words, our study suggests that the way athletes with disabilities perceive their errors can be an antecedent variable that can alter their challenges and actual performance (deliberate practice).

6 Limitation and future directions

Our study had several limitations. First, although the participants in our study included athletes with physical and hearing disabilities, we did not control for differences between these two groups. The results may vary depending on the severity or type of the disability. Therefore, future research should classify athletes with disabilities into separate groups and conduct multigroup analyses to verify the differences in the research model. Second, because our study focused on Taekwondo athletes with disabilities, there are limitations in applying the findings to non-disabled populations. Third, we concentrated on the variables related to the perception of errors, challenges, and deliberate practice. However, further efforts are required to strengthen and generalize our research model. For example, a more detailed analysis is required to understand the role of challenges (e.g., mediating or moderating effects) in the relationship between perception errors and deliberate practice among athletes with disabilities. Additionally, expanding the model by incorporating variables related to performance is expected to provide further insights. Fourth, there are limitations to the measurement tools. The tools used in this study were adapted for athletes with disabilities, using tools originally designed for non-disabled athletes. Although there were no issues with content validity, the measurement items were not specifically developed for athletes with disabilities and thus may not fully capture the constructs. Therefore, future research should focus on developing items to assess the perception of errors, challenges, and deliberate practices, particularly for athletes with disabilities.

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 authors.

Ethics statement

This study complied with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) checklist and the study protocol was approved by the Institutional Review Board at the Wonkwang University and was performed in compliance with the Helsinki Declaration and ethical research principles (WKIRB-202211-SB-111). 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

YS: Conceptualization, Funding acquisition, Methodology, Supervision, Validation, Visualization, Writing – original draft. JS: Investigation, Resources, Writing – original draft. SK: Methodology, Writing – original draft. ES: Conceptualization, Data curation, Formal analysis, Methodology, Project administration, Software, Writing – original draft. M-SH: Funding acquisition, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

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Classification of recovery states in U15, U17, and U19 sub-elite football players: a machine learning approach

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Introduction: A promising approach to optimizing recovery in youth football has been the use of machine learning (ML) models to predict recovery states and prevent mental fatigue. This research investigates the application of ML models in classifying male young football players aged under (U)15, U17, and U19 according to their recovery state. Weekly training load data were systematically monitored across three age groups throughout the initial month of the 2019–2020 competitive season, covering 18 training sessions and 120 observation instances. Outfield players were tracked using portable 18-Hz global positioning system (GPS) devices, while heart rate (HR) was measured using 1 Hz telemetry HR bands. The rating of perceived exertion (RPE 6–20) and total quality recovery (TQR 6–20) scores were employed to evaluate perceived exertion, internal training load, and recovery state, respectively. Data preprocessing involved handling missing values, normalization, and feature selection using correlation coefficients and a random forest (RF) classifier. Five ML algorithms [K-nearest neighbors (KNN), extreme gradient boosting (XGBoost), support vector machine (SVM), RF, and decision tree (DT)] were assessed for classification performance. The K-fold method was employed to cross-validate the ML outputs.

Results: A high accuracy for this ML classification model (73–100%) was verified. The feature selection highlighted critical variables, and we implemented the ML algorithms considering a panel of 9 variables (U15, U19, body mass, accelerations, decelerations, training weeks, sprint distance, and RPE). These features were included according to their percentage of importance (3–18%). The results were cross-validated with good accuracy across 5-fold (79%).

Conclusion: The five ML models, in combination with weekly data, demonstrated the efficacy of wearable device-collected features as an efficient combination in predicting football players' recovery states.

KEYWORDS
youth soccer, recovery, GPS, perceived exertion, AI

1 Introduction

Classifying recovery states in young football players who are still developing physically and mentally is crucial to ensure a high performance, reduce the injury risk, and enhance a better fatigue management (Rico-González et al., 2022b; Kellmann et al., 2018). Recovery management for under (U)15, U17, and U19 male football players must consider various physiological, psychological, and external factors that influence the effectiveness of rest and recuperation periods (Teixeira et al., 2022a; Teixeira et al., 2022b). Proper assessment and monitoring of recovery states can yield vital information about players' readiness and overall health, thereby guiding coaches in tailoring training loads and recovery protocols more effectively (Teixeira et al., 2023; Helwig et al., 2023). The increasing demands on young football players, including frequent training sessions and competitive matches, place substantial strain on their bodies (Parr et al., 2021; Towlson et al., 2021).

Effective recovery strategies are essential to mitigate this strain and support the physiological adaptations that underpin performance improvements (Lee et al., 2023; Silva et al., 2022), which can help manage the physical and psychological stresses associated with intensive training and competition schedules (Teixeira et al., 2023; Howle et al., 2020). Optimizing recovery is crucial for youth players, whose bodies are still growing and developing, to support healthy development and avoid long-term health issues (Nobari et al., 2021; Clemente et al., 2021). Inadequate recovery and training intensity management during the microcycle can lead to overtraining syndrome, characterized by persistent fatigue, performance decline, and a heightened risk of injury (Ramos-Cano et al., 2022). Wearable technology has revolutionized the sports science field, providing insights into recovery states (Nobari et al., 2021; Clemente et al., 2021). Devices that monitor heart rate (HR)—a key indicator of autonomic nervous system function and recovery status—are now commonplace in youth sports settings (Teixeira et al., 2022a; Santos et al., 2021). Furthermore, wearable devices can track movement patterns and physical exertion using accelerometers and global positioning system (GPS) technology (Gómez-Carmona et al., 2021; Oliva-Lozano et al., 2020), providing detailed information on distances covered, speeds attained, and the intensity of movements during training and competition. Such comprehensive data collection offers a holistic view of an athlete's workload and recovery needs (Oliva-Lozano et al., 2020).

The integration and analysis of this multifaceted data pose significant challenges, necessitating advanced analytical methods (Hessels et al., 2020). Machine learning (ML) has emerged as an artificial intelligence (AI) approach in this context, capable of analyzing vast and complex datasets to identify patterns and make predictions that traditional statistical methods might miss (Majumdar et al., 2022; Sarker, 2021). ML algorithms can process diverse data inputs, such as physiological demands and performance metrics, to classify and predict recovery outcomes (King et al., 2022; Filipas et al., 2020; Bourdon et al., 2017). This capability allows for a more sophisticated understanding of how different factors interact to influence recovery states, which is particularly significant in young athletes (King et al., 2022; Filipas et al., 2020; Bourdon et al., 2017). Recent studies highlight the effectiveness of ML models in predicting training load, recovery, and injury risks in football players (Vallance et al., 2023; Pillitteri et al., 2023; Rossi et al., 2022; Vallance et al., 2020). Vallance et al. (2023) demonstrated that tree-based models significantly improved perceived exertion predictions by 60%, with past RPE values being the strongest predictors. Pillitteri et al. (2023) demonstrated significant negative correlations between training load, recovery states, and model availability according to the training day. Rossi et al. (2022) emphasized the utility of the ML approach in predicting players' wellness by integrating workload history, while Vallance et al. (2020) found that combining internal and external load features enhanced long-term injury risk prediction. All studies highlight the potential of ML for personalized training planning and injury prevention in football contexts (Vallance et al., 2023; Pillitteri et al., 2023; Rossi et al., 2022; Vallance et al., 2020).

However, ML is still being researched to manage recovery status in young sub-elite football players. Most studies focus on elite football players (Vallance et al., 2023; Oliver et al., 2020), leaving a critical need to investigate how training load and recovery variables manifest in different age groups and competitive levels (Teixeira et al., 2021a; Teixeira et al., 2022e). In addition, the application of ML models to classify recovery states in young footballers is still underexplored despite its potential to improve injury understanding and fatigue prediction (Teixeira et al., 2022e; Oliveira, 2023). This research has sought to address this gap by using training data to develop predictive models that optimize performance and wellbeing in sub-elite youth football players (Díaz-García et al., 2022; Coutinho et al., 2018). More specifically, this research aims to investigate the use of ML models in the classification of recovery states in sub-elite male football players in the U15, U17, and U19 age groups.

2 Methodology

2.1 Participants

A total of 20 U15 players (age: 13.2 ± 0.5 years; height: 1.69 ± 0.78 m; weight: 55.7 ± 9.4 kg), 20 U17 players (age: 15.4 ± 0.5 ± 1.2 y; height: 1.8 ± 0.5 m; weight: 64.38 ± 6.6 kg), and 20 U19 players (age: 17.39 ± 0.55 ± 1.8 ± 0.7 y; height: 1.82 ± 0.01 m; weight: 68.9 ± 8.4 kg) were observed for 2 weeks in a sub-elite Portuguese football academy. In the 2019–2020 competition season, the three age groups' daily training loads were regularly observed. All participants were fully informed about the study's purpose and potential risks in line with ethical standards. Informed consent was obtained from each participant or their guardian in the case of minors. The study protocol was approved by the local Ethics Committee at the University of Trás-os-Montes e Alto Douro (3379-5002PA67807).

2.2 Study design

The weekly training load was consistently monitored across three age groups during the first month of the 2019–2020 competitive season. The training data spanned a 6-week period, covering 18 training sessions and 324 observations (U15 = 41, U17 = 20, and U19 = 26 observations, respectively). Individual datasets were considered eligible if the player adhered to a one-game-per-week schedule and fully participated in the training sessions. The training cycle consisted of three weekly sessions, each lasting approximately 90 min, with match data excluded from the analysis. Training days were classified using the "match day minus format" (MD): MD-3 (Tuesday), MD-2 (Wednesday), and MD-1 (Friday). On average, each session involved 18 players. Each tier had week 1 (Week_1) and week 2 (Week_2) coded.

All age groups trained on outdoor pitches of official dimensions (FIFA standard; 100 × 70 m) with synthetic turf, held between 10:00 AM and 8:00 PM under similar environmental conditions (14–20°C; relative humidity 52–66%).

2.3 Procedures

Outfield players were tracked using portable GPS devices (STATSports Apex®, Northern Ireland) throughout each training session. The GPS units, sampling at 18 Hz, provided raw data on position, velocity, and distance and included an accelerometer (100 Hz), magnetometer (10 Hz), and gyroscope (100 Hz). Each player wore the micro-technology in a mini pocket of a custom-made vest provided by the manufacturer, positioned on the upper back between the scapulae. All devices were activated 30 min before data collection to ensure a clear satellite signal reception (Teixeira et al., 2021b; Beato et al., 2018). A 1-Hz short-range telemetry system was used to measure the heart rate (Garmin International, Inc., Olathe, KS, USA). The Rating of Perceived Exertion (RPE) scale was used to evaluate perceived exertion (Cabral et al., 2020). The total quality recovery (TQR) score proposed by Kenttä and Hassmén (1998) was applied to measure athletes' recovery perception. The TQR was used before the start of the training session, while the RPE was applied after the end of the training session. The application steps were previously explained to the players, and a Microsoft Excel® spreadsheet was used to gather perceived exertion and recovery (Microsoft Corporation, USA) (Haddad et al., 2017).

2.4 Variables

The ML algorithms were built integrating age categories, anthropometric measures, GPS-based parameters, HR-based variables, and perceived exertion scales. Table 1 shows each included variable as well as the type of variable, the encoding label, and the average values.

2.4.1 Physical parameters

External training load was measured using time-motion data, including total distance (TD) covered (m), average speed (AvS), maximal running speed (MRS) (m/s), relative high-speed running (rHSR) distance (m), high metabolic load distance (HMLD) (m), sprinting (SPD) distance (m), dynamic stress load (DSL), number of accelerations (ACC), and number of decelerations (DEC). The GPS software provided data on locomotor categories above 19.8 km/h: rHSR (19.8–25.1 km/h) and SPD (>25.1 km/h). Sprints were tracked by number and average sprint distance (m). HMLD, a metabolic variable, represents the distance covered by a player when the metabolic power exceeds 25.5 W/kg. HMLD encompasses all high-speed running and accelerations and decelerations above 3 m/s^2. Both acceleration variables (ACC/DEC) accounted for movements in the maximum intensity zone (>3 m/s^2 and < 3 m/s^2, respectively). DSL was assessed using a 100 Hz triaxial accelerometer integrated into the GPS devices, measuring the sum of accelerations across the three orthogonal axes of movement (*X*, *Y*, and *Z* planes), expressed as G force (Teixeira et al., 2021b; Beato et al., 2018).

TABLE 1 The variables included in the ML algorithm build.

Variable	Type of variable (Encoding or mean ± SD)
Age category (U-17, U-15 or U-19)	Binary numeric (positive = 1, negative = 0)
Height (meters)	Continuous numeric (1.73 ± 0.07)
Body weight (kg)	Continuous numeric (63 ± 10)
BMI (kg/m^2)	Continuous numeric (20.6 ± 2.13)
Week (Week 1 or 2)	Binary numeric (positive = 1, negative = 0)
Position (CD, CM, FW, FB, WM)	Binary multiclass (combination of 0,1 sequences)
Total distance (meters)	Continuous numeric (5,317 ± 1,628)
rHSR (meters)	Continuous numeric (87 ± 78)
HMLD (meters)	Continuous numeric (560 ± 289)
AvS (repetitions)	Continuous numeric (51 ± 24)
SPR (repetitions)	Continuous numeric (7 ± 2)
DSL (repetitions)	Continuous numeric (252 ± 134)
ACC (repetitions)	Continuous numeric (46 ± 22)
DEC (repetitions)	Continuous numeric (42 ± 24)
Cal (kcal)	Continuous numeric (1,046 ± 354)
RPE (index)	Continuous numeric (13 ± 2)
TQR (index)	Continuous numeric (16 ± 2)
TQR_Class (recovery status)	Binary numeric (bad recovery = 1, good recovery = 0)

ACC, accelerations; AvS, average speed; Cal, Calories; CD: Central defenders; CM, central midfielders; DEC, decelerations; DSL, Dynamic stress load; FB, fullbacks; FW, forwards; HMLD, high metabolic load distance; rHSR, relative high-speed running; RPE, rating of perceived exertion; SPR, sprinting; TQR, total quality recovery; U, Under; WM, wide midfielders.

2.4.2 Heart rate

The HR and perceived exertion were applied to measure the recovery state. The maximum heart rate (HR_{max}), average heart rate (AvHR), and percentage of HR_{max} (%HR_{max}) were HR-based variables. HR_{max} was obtained by Yo–Yo Intermittent Recovery Test Level 1 (YYIR1) (Aquino et al., 2020). Training impulse (TRIMP) was obtained using the procedures suggested by Akubat et al. (2012). The TRIMP was calculated by multiplying training duration (min) intensity ($\Delta HR = AvHR - HR_{rest}/HR_{max} - HR_{rest}$), which was weighted according to the fractional elevation in heart rate and blood lactate concentration (Akubat et al., 2012):

$$\text{TRIMP} = \text{training} \times \Delta HR \times 0.2053\, e^{3.5179 \Delta HR}$$

2.4.3 Perceived exertion

The RPE and TQR were obtained using a scale from 6 to 20 to assess players' perceived effort and recovery states, respectively (Brink et al., 2010). A 2-week familiarization with both scales was conducted before the study. Data were collected individually by the same researcher during GPS device removal to prevent peer influence on recovery and effort perception (Kenttä and Hassmén, 1998; Haddad et al., 2017). A Microsoft Excel® spreadsheet (Microsoft Corporation, USA) was used to gather perceived data.

2.4.4 Body composition

The height (m), weight (kg), chronological age (years), sitting height (cm), and level of experience (years) of the layers were recorded at each measurement point. Body mass index (BMI) was calculated by dividing weight by the square of height (kg/m^2) (Teixeira et al., 2022a).

2.4.5 Data preprocessing and normalization

We utilized the computational programming language PythonTM (Python, 2023), where the libraries "seaborn," "matplotlib.pyplot," "numpy," and "pandas" were enabled to import, visualize, and conduct the necessary data transformations (Unpingco, 2016). The recovery state collected by the TQR score was targeted as a binary level (0 = well-recovered; 1 = insufficient recovery). Following the cutoffs suggested by Kenttä and Hassmén (1998), the positive label was considered with values <13 points in the TQR scale. To ensure that the classes would be well-defined and facilitate the decision boundaries characterization by the ML algorithms, we defined the negative value only for that player with scores equal to 19–20 in the TQR scale, or else, making that the points for insufficiently recovered and the well-recovered were far away from each other (More and Ingman, 2008). After applying this cutoff from the initial dataset (60 football players × 2 weeks = 120 observations), only 36 football players were included in the underlined criteria for positivity (n = 18 participants with TQR scores <13 points) or negativity (n = 18 participants with TQR scores approximately 19–20 points). To make possible the consideration of all features in calculating the importance, those features with a categoric nature were converted into numeric binary arrays using the one-hot encoding (Hancock and Khoshgoftaar, 2020). Next, the feature selection was performed using two different steps: the first step was performed where a correlation matrix was applied to identify the most correlated features and reduce dimensionality problems within the dataset, and in the second step, the random forest (RF) classifier was used to identify non-linear relationships between the most correlated features and thus build a more comprehensive panel of predictors of the football players' recovery states. In the second step of the feature selection process, the "train_test_split" function was activated from the "sklearn" library, considering 70% of the dataset for training (n = 25) and 30% for testing (n = 11).

Furthermore, we employed the package "from sklearn.preprocessing import StandardScaler" to normalize the data after observing significant differences between the feature's numerical scales and turned on the "StandardScaler" function (Unpingco, 2016; Biamonte et al., 2017). The characteristics were scaled within a range of −1,1 to facilitate easier interpretation of the sigmoid function as part of the normalizing process $\sigma(x) = \frac{1}{1+e^{-x}}$ [with binary data (0,1)], where "e" is the numerical basis of the classification algorithm and "x" is the independent variable (2.71828) (Narayan, 1997).

2.4.6 Classifying algorithms

To perform the football players' recovery state classification, we applied the rerun of the "train_test_split" function, also considering the same splitting setup [70% for training (n = 25); 30% for testing (n = 11)] (Unpingco, 2016; Cai et al., 2018). To guarantee reproducibility between various runs of the same code, we employed a random seed of 0 for all algorithms. Next, five ML classifiers were implemented using the libraries "sklearn.neighbors import KNeighborsClassifier" [(Rico-González et al., 2022b) for K-nearest neighbors classifier (KNN)], "from sklearn.ensemble import GradientBoostingClassifier" [(Kellmann et al., 2018) for Gradient Boosting Classifier (XGbosst)], "from sklearn.svm import SVC" [(Teixeira et al., 2022a) for support vector machine (SVM)], "from sklearn.ensemble import RandomForestClassifier" [(Teixeira et al., 2022b) for RF], and "from sklearn.tree import DecisionTreeClassifier" [(Teixeira et al., 2023) for DT Classifier] were activated to apply the algorithms and perform the recovery state classification (Python, 2023; Unpingco, 2016; Haslwanter, 2016; Pedregosa et al., 2011). Since all ML classifiers have limitations and strengths, the five ML classifiers were chosen in the present study aiming to verify the stability among different models to ensure that there were no overfitting and underfitting, thus testing their robustness to generalize to unseen datasets (Pedregosa et al., 2012; Kursa and Rudnicki, 2011).

The functions for accuracy, precision, recall, and F1-score were activated by activating the library "from sklearn.metrics import accuracy_score, confusion_matrix, classification_report" to assess the models (Hicks et al., 2022; Jierula et al., 2021). The following is a complete description of the algorithms and the corresponding assumptions:

2.4.7 K-nearest neighbors classifier

A data point is classified by the KNN classifier in the feature space based on the majority class among its KNN (Uddin et al., 2022). The equation exemplifies KNN:

$$y = \text{mode}\left(y_{\text{neighbors}}\right)$$

where

- y is the predicted class label;
- $y_{\text{neighbors}}$ is the class labels of the k-nearest neighbors; and
- ***mode*** is the most frequently occurring class label among the neighbors.

2.4.8 Gradient boosting classifier

The XGBoost classifier is the algorithm that builds a sequence of trees in which the new tree corrects the errors of the previous trees by minimizing a loss function (Natekin and Knoll, 2013). This is the XGBoost equation expressed as follows:

$$F_m(x) = F_m - 1(x) + \gamma_m h_m(x)$$

where

- $F_m(x)$ is the prediction of the mth model;
- $F_m - 1(x)$ is the prediction of the $(m-1)$th model;
- γ_m is the learning rate, which scales the contribution of each tree; and
- h_m is the mth weak learner (usually a DT).

2.4.9 Support vector machine

SVM classifier locates the hyperplane in the feature space that most effectively divides the classes with the greatest margin (Cervantes et al., 2020). The SVM was expressed by

$$minimize\left(\frac{1}{2}\|w\|^2\right)\text{subject to } yi\left(w.x_i + b\right) \geq 1$$

where

- w is the weight vector that defines the hyperplane;
- b is the bias term;
- y_i is the class label of the ith training sample;
- x_i is the feature vector of the ith training sample; and
- $w \cdot x_i + b$ is the decision function that calculates the distance from the hyperplane.

2.4.10 Random forest classifier

The RF classifier builds several DTs and outputs the mode of the classes for classification (Breiman, 2001). The equation can be expressed by

$$y = \text{model}\left(\{h_t(x)\}\ _r^T = 1\right)$$

where

- y is the predicted class label;
- h_t is the prediction from the tth DT;
- T is the total number of trees in the forest; and
- *mode* is the most frequently occurring class label among the trees' predictions.

2.4.11 Decision tree classifier

To maximize the separation of classes at each node, the DT classifier essentially operates by dividing the data into subgroups based on the most relevant feature (Song and Lu, 2015). DT is characterized by the following equation:

$$\text{split criterion} : \text{Gini}(t) = 1 - \sum_{i=1}^{n} p_i^2$$

where

- Gini(t) is the Gini impurity for a node t;
- n is the number of classes; and
- p_i is the probability of a randomly chosen element being classified as class i at node t.

2.4.12 Model evaluation

To assess the model's performance, we used the metrics accuracy, precision, recall, and F1-score, as explained in the following (Hicks et al., 2022):

(1) Accuracy score: Accuracy measures the proportion of correctly classified instances among all instances. It is calculated as the ratio of correctly predicted instances (true positives and negatives) to the total number of instances (Hicks et al., 2022).

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN}$$

where TP = true positives; TN = true negatives; FP = false positives; and FN = false negatives.

(2) Precision: Precision measures the proportion of predicted positive instances that are correctly classified. It is calculated as the ratio of true positives to the sum of true positives and false positives (Hicks et al., 2022).

$$\text{Precision} = \frac{TP}{TP + FP}$$

(3) Recall: Sensitivity, also known as recall or true positive rate, measures the proportion of actual positive instances that the model correctly predicts. It is calculated as the ratio of true positives to the sum of true positives and false negatives (Hicks et al., 2022).

$$\text{Recall} = \frac{TP}{TP + FN}$$

(4) F1-score: The F1-score is the harmonic mean of precision and recall, providing a single metric that balances both measures. It is calculated using the precision and recall values, combining them into a single value (Hicks et al., 2022).

$$\text{F1} - \text{score} = 2 \times \frac{\text{PPV} \times \text{Recall}}{\text{PPV} + \text{Recall}}$$

To evaluate the models' stability in the classification task, we employed K-fold cross-validation. This method divides the original dataset into K distinct subsets, where each subset is alternately used as a validation set while the remaining subsets are used for training. This approach assesses how consistently the models perform across different segments of the dataset, ensuring the robustness of the results (Wong, 2015). For this evaluation, we tested 5-fold of the original X array used in the training and testing processes of the five ML classifiers (Rodriguez et al., 2010). This approach allowed us to evaluate the consistency of the classifications.

3 Results

Figure 1 shows the correlation coefficient of each independent variable with the TQR classes. In this way, we consider a panel consisting of only variables that presented at least small correlation coefficients with the target variable, fitting the dataset with the variables U19, U15, BMI, ACC, DEC, Week_1, Week_2, SPD, and RPE. These features were filtered within a new dataset, where they were considered for the final feature selection process with an RF classifier.

Next, the RF algorithm presents a very good classification report (accuracy = 92%; recall = 91%; and F1-score = 91%), with a good validation report after passing the same array within the 5-fold cross-validation (accuracy range = 71–87%; standard deviation = 12%; and average accuracy = 83%). Table 1 shows the classification report for the second step of feature selection with an RF classifier.

Figure 2 shows the best ranking of features captured by RF, reporting that the best features were U19 (18%) and U15 (15%) age categories, and the RPE (3%) presented the weaker contribution.

After reducing the data dimensionality, we implemented the five ML algorithms considering the panel of best features hierarchically reported as follows: U19, U15, BMI, ACC, DEC, Week_1, Week_2, SPD, and RPE. Table 2 shows that the algorithm's performance ranged from 73–100% (Table 2).

Table 3 compiled the cross-validation of the algorithm's performance, which with an average performance of 79% validated and pointed to good generalization performance of the panel of features collected with wearable devices in predicting the football player's recovery state (Table 4).

4 Discussion

The primary objective of this study was to investigate the use of ML models in the classification of male football players in the U15–17 and U19 age groups for recovery states. The key parameters offer a detailed picture of the physical and mental demands placed on players during training sessions. After reducing the data dimensionality, we implemented the ML algorithms considering a panel of 9 variables (U19, U15, BMI, ACC, DEC, Week_1, Week_2, SPD, and RPE). The 9 features were included according to their percentage of importance (3–18%). As the main results, we got good (73%) to very good (100%) in identifying football players' recovery state based on the 10 feature panel football.

The correlation analysis revealed that several variables exhibited significant correlations with the target variable (TQR). These variables, including age categories, BMI, acceleration, deceleration, training weeks, speed, and both subjective and objective RPE, were selected for further analysis using the RF classifier. The RF algorithm demonstrated strong predictive performance, achieving an accuracy of 92% and an F1-score of 91%. Cross-validation further validated the model's generalization ability, with an average accuracy of 83% across 5-fold. Feature importance analysis identified age categories as the most

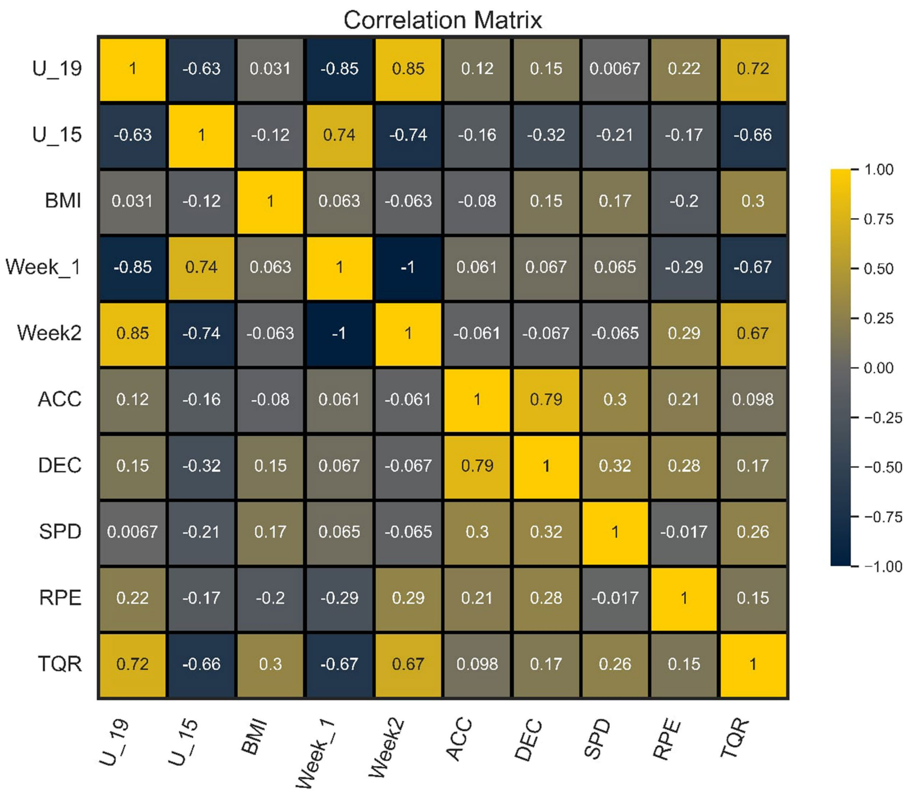

FIGURE 1
Correlation heatmap of features and TQR classes. ACC, accelerations; BMI, body mass index; DEC, decelerations; RPE, rating of perceived exertion; SPD, sprint distance; U_15, under 15; U_19, under 19; Week_1, first weekly training load; Week_2, second weekly training load.

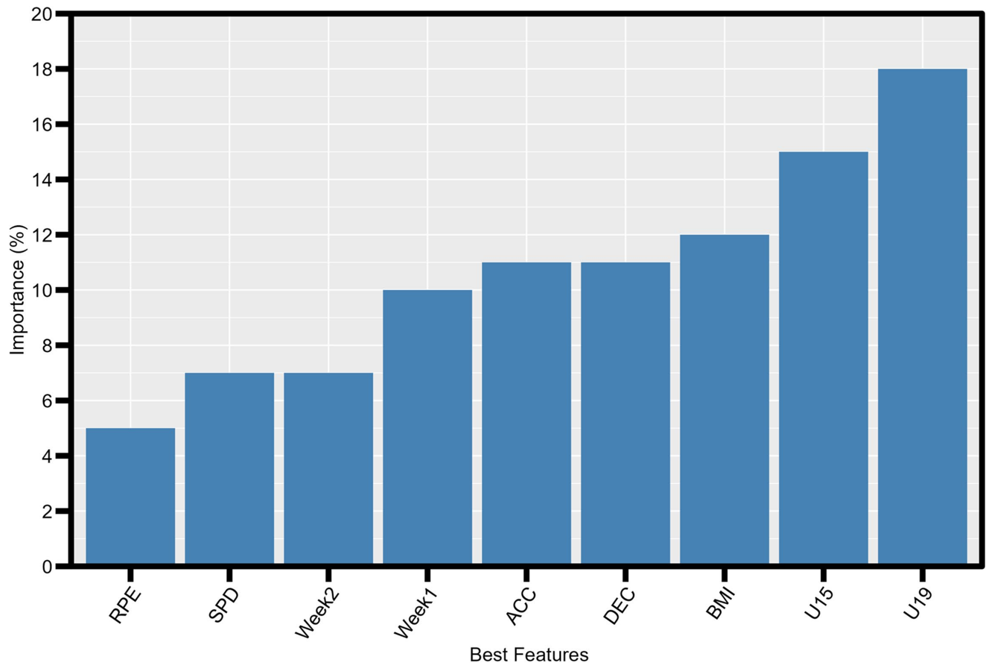

FIGURE 2
Best features to classify the soccer player's recovery state. Data are displayed in percentage of importance. ACC, accelerations; BMI, body mass index; DEC, decelerations; RPE, rating of perceived exertion; SPD, sprint distance; U_15, under 15; U_19, under 19; Week_1, first weekly training load; Week_2, second weekly training load.

TABLE 2 Detailed classification of random forest (RF) algorithm applied to feature selection.

	Precision	Recall	f1-score	Support
Class				
0	1.00	0.80	0.89	5
1	0.86	0.100	92	6
Metrics				
Accuracy			0.91	11
Macro avg	0.93	0.90	0.91	11
Weighted avg	0.92	0.91	0.91	11

Avg, average.

influential predictors, followed by RPE. Drawing from theoretical underpinnings and insights from existing studies in this area, the selected variables for the panel included SPR, HMLD, DSL, AvS, and ACC. These variables exhibited percentage importance ranging from 3 to 18%, signifying their significant relevance in predicting players' recovery states. Implementing ML algorithms using this panel of five variables yielded varied performances. Both RF and DT algorithms demonstrated exceptional performance, each with an accuracy of 99%. This high performance can be attributed to the ability of these algorithms to effectively handle the complexity and non-linearity of the data, as well as their robustness to data variability. Furthermore, the insights from the existing literature focusing on applying ML in football contexts, training load monitoring, and related areas emphasize the importance of data-driven approaches and algorithm selection. Techniques such as RT and DT have been widely recognized for their effectiveness in sports analytics due to their ability to handle complex datasets and provide interpretable results. XGBoost, another algorithm utilized in this study, also exhibited high performance with an accuracy of 96%. This underscores its efficacy as a boosting technique that enhances predictive accuracy by combining multiple weak models into a robust model. In contrast, KNN and SVM algorithms demonstrated lower performances, with 51 and 40% accuracy, respectively. These findings suggest that KNN and SVM may not be as effective in dealing with the complexity of the training data collected via wearable devices. Recent advancements in sports science have significantly enhanced the analysis and monitoring of football players' performance and wellbeing (Nobari et al., 2021; Clemente et al., 2021). Standard methods for analyzing player movement and fatigue, such as perceived exertion scales and heart rate monitors, have proven effective and accessible (Kenttä and Hassmén, 1998). These tools provide practical means for regularly assessing psychophysiological fatigue and performance changes during training and matches (Cabral et al., 2020).

The subsequent application of five ML algorithms to the selected features yielded consistent and promising results. All algorithms achieved accuracies ranging from 73 to 100%, with an average performance of 95%. The cross-validation confirmed the generalization performance of these models, demonstrating their ability to predict recovery states in football players based on the collected features. These findings suggest that a combination of age-related factors, physiological metrics, and subjective perceived assessments can effectively predict recovery states in young football players. This value reflects the weighted average accuracy of the different algorithms used in the study. While the individual top performances of RF and DT are noteworthy, the overall weighted average is influenced by the relatively lower performances of KNN and

TABLE 3 Algorithm's performance in classifying football's fatigue states.

Algorithm	Accuracy (%)	Precision (%)	Recall (%)	F-1 score (%)	Average metrics
KNN	100	100	100	100	100
XGboost	73	74	73	73	73
SVM	100	100	100	100	100
RF	100	100	100	100	100
DT	100	100	100	100	100
Algorithm's Aver.	95	95	95	95	95

KNN, k-Nearest Neighbors; XGBoost, Gradient Boosting Gradient Boosting Classifier; SVM, Support Vector Machine; RF, Random Forest Classifier; DT, Decision tree Classifier; Algorithm's Aver, general algorithm's average.

TABLE 4 Outputs of the cross-validation of the classifying models' performance.

Algorithm	Accuracy (%)	Accuracy Sub.1 (%)	Accuracy Sub.2 (%)	Accuracy Sub.3 (%)	Accuracy Sub.4 (%)	Accuracy Sub.5 (%)	SD (%)
KNN	83	87	71	85	71	100	11
XGboost	75	75	57	71	71	100	14
SVM	75	62	71	71	71	100	13
RF	83	87	85	71	71	100	11
DT	78	75	71	57	85	100	14
Overall Performance ($\bar{x}$)	79	77	71	71	74	100	13

Sub., subsets from the entire X array; SD, standard deviation; $\bar{x}$., arithmetical average; KNN, k-Nearest Neighbors; XGBoost, Gradient Boosting Gradient Boosting Classifier; SVM, Support Vector Machine; RF, Random Forest Classifier; DT, Decision tree Classifier; Algorithm's Aver, general algorithm's average.

SVM algorithms. Therefore, practical applications should consider not only individual performance but also the robustness and consistency across different scenarios when selecting ML algorithms. ML models can achieve relatively high accuracy in predicting outcomes or analyzing data, and their performance can vary significantly depending on the specific algorithm used. In this study, the overall performance of the ML models, as indicated by a compiled algorithm performance table, was 74.5%, reflecting a weighted average accuracy. Therefore, when applying ML models in practical sports science scenarios, it is essential to consider not just the highest performing algorithms but also the robustness and consistency across various conditions and datasets (Unpingco, 2016; Cai et al., 2018). This comprehensive approach ensures that the chosen ML model performs reliably under different circumstances, enhancing its practical utility in sports science applications (Hicks et al., 2022; Jierula et al., 2021).

However, the study also highlights the variability in individual responses to training loads. The age group was a significant predictor of recovery status in a study that identified essential variables, including U19, U15, BMI, ACC, DEC, Week_1, Week_2, SPD, and RPE. Recent studies have demonstrated the effectiveness of these models in classifying young football players' recovery states based on data collected from wearable devices (Majumdar et al., 2022; Rico-González et al., 2022a; Teixeira et al., 2024). This finding is consistent with the systematic study, highlighting the importance of integrating subjective wellness and training load indicators (Vallance et al., 2023; Herold et al., 2019). The RF classifier demonstrated these models' reliability across various expertise levels, achieving an accuracy of 92% on the training set and maintaining an average accuracy of 83% in 5-fold cross-validation. This finding is consistent with a systematic review, highlighting the importance of integrating training load data with perceived wellness to improve predictive accuracy in football (Rico-González et al., 2022a). Majumdar et al. (2022) also observed that despite interpretability issues, black-box models such as RF often outperform other methods in predicting relationships between workload and injuries in football. Such insights are vital for developing customized training and recovery plans for individual athletes. Furthermore, feature importance analysis from the study highlighted the significant role of perceived exertion in recovery predictions to understand player development and injury prevention (Teixeira et al., 2024). The focus on subjective measures such as RPE and its link to objective training loads is further supported by research showing that wellness questionnaires can enhance monitoring in football (Calvo, 2019; García-Aliaga et al., 2021; Calvo et al., 2019). Moreover, testing different ML algorithms on a reduced feature set validated the effectiveness of the selected variables in predicting recovery states and fatigues with consistently strong accuracy (Calvo, 2019; Calvo et al., 2019). Calvo et al. (2019) recently reported that mental load influences recovery states, impacting decision-making, technical performance, and physical outputs. Changing the scoring structure during football practice has a substantial impact on the physical and mental strain of players; this effect is more pronounced in shorter games than in possession drills (Calvo, 2019). Fatigue can be effectively managed by modifying psychological content, task features, coaching behaviors, and competitive structure (Miguel et al., 2021; Oliveira et al., 2021). Further research should add variables to measure central and peripheral fatigue to compare them with recovery states and the possible value of perceived fatigability (Alba-Jiménez et al., 2022).

Despite a standardized training regimen, players exhibited different levels of perceived exertion and recovery (Teixeira et al., 2022a; Teixeira et al., 2022e). This variability underscores the need for individualized training plans that cater to the unique needs and capacities of each player. Coaches and sports scientists should consider these individual differences when designing training programs to optimize performance and reduce the risk of injury. Environmental conditions, such as temperature and humidity, were kept relatively consistent during the training sessions (Taylor et al., 2010). This controlled environment ensured that external factors did not unduly influence the training loads and recovery metrics. Nevertheless, the future studies could explore the impact of varying environmental conditions on training and recovery to provide more comprehensive guidelines for training under different climates. The findings from this study indicate that the training loads were systematically managed, with a clear structure to the training microcycle. The findings emphasize the importance of individualized training approaches and the need for ongoing monitoring to ensure the health and performance of young athletes (Howle et al., 2020). In addition, the results of this study provide valuable insights into the relative importance of independent variables in the dataset and their contribution to predicting the recovery state of football players using ML algorithms (Teixeira et al., 2023; Howle et al., 2020). This variable selection was crucial for reducing data dimensionality and facilitating the efficient implementation of ML algorithms. U19, U15, BMI, ACC, DEC, Week_1, Week_2, SPD, and RPE are crucial for predicting training demands in sub-elite young footballers.

4.1 Practical applications, the future research, and limitations

The future research should continue to explore the interplay between training load, recovery, and performance, incorporating a wider range of variables and more extended observation periods along the season. The integration of advanced monitoring technologies, such as GPS and accelerometers, has revolutionized the way training loads are assessed in sports (Hessels et al., 2020). These tools offer validated accuracy and granularity, allowing for more informed decision-making in training design and load management (Teixeira et al., 2021b; Teixeira et al., 2022d). The use of high-frequency sampling devices in this study ensured that even the subtle nuances of player movement and exertion were captured, providing a robust dataset for analysis. The RPE provided an additional layer of understanding by quantifying the subjective effort perceived by the players (Chang et al., 2020; De Meester et al., 2020). This measure is particularly useful for assessing internal load and ensuring that training intensities are aligned with the players' physical capacities (Rico-González et al., 2022b; Sallen et al., 2020). The use of RPE has been validated in numerous studies and is recognized as a reliable indicator of training load in football (Teixeira et al., 2022c; Ferraz et al., 2022). All these variables are high-intensity variables, so monitoring them is essential to describe their impact to predict recovery states and prevent fatigue (Alba-Jiménez et al., 2022). This point plays a fundamental role in the application of complementary training methodologies associated with Strength and Conditioning, such as concurrent training (Seipp et al., 2023), plyometric (Gherghel et al., 2021), or strength, agility, and quickness (SAQ) (Trecroci et al., 2016; Trecroci et al., 2022). Moreover, the RPE session values could be another strategy for refining the recovery states classification model and to further individualize the training load. Another potential limitation, as the article currently stands, could be that a preliminary test was not conducted to determine the relationship between HR and lactate levels. This may have resulted in TRIMP not being a reliable predictor of recovery or fatigue. Thus, extending the monitoring periods over different seasons and including data from real match contexts may help to better understand long-term fatigue and recovery patterns. Thus, the future studies could incorporate other variables, such as biochemical markers, sleep patterns, and psychological measures, to enhance the predictive power of recovery models. The inclusion of biochemical data (stress and inflammation) and sleep patterns could also be very valuable for more profound comprehension of the recovery state during the weekly training process of football players during different sportive seasons (Branquinho et al., 2024a; Branquinho et al., 2024b).

In fact, using more advanced modeling, such as deep learning and time series approaches, could improve prediction accuracy. In addition, incorporating technical and tactical performance metrics alongside recovery data could provide more comprehensive insights into player readiness. The importance of age-related suggests that recovery management protocols should be tailored to specific age groups to ensure optimal recovery. The integration of GPS, HR data, and perceived exertion provides valuable insights that can be used to monitor recovery states during the season. Furthermore, these enhancements could further refine models and algorithms for recovery protocols and injury prevention strategies in youth football.

As research limitations, data were collected from the unreal context of football matches. There is a lack of longitudinal data that would help to understand long-term patterns of fatigue and recovery state among football players. In addition, the predictor explained between 3 and 18% of recovery status, suggesting that additional predictors could improve the accuracy of the model. In fact, the low training frequency per week (3 days vs. 4 days without activity) makes it essential to monitor other activities outside the training period to understand the influence of fatigue and the ability of the models studied to explain recovery. Thus, additional longitudinal data are essential in training algorithms that are more representative of young football players. More specifically, we need to understand the effects of recovery states on other vital dimensions, such as technical and tactical performance at different levels, ages, and development stages (De Meester et al., 2020; Branquinho et al., 2024a).

5 Conclusion

In conclusion, the five ML models, in combination with weekly data, demonstrated the efficacy of wearable device-collected features as an efficient combination in predicting sub-elite young football players' recovery states. Critical variables were identified by feature selection, and 10 variables—body mass, U15, U19, accelerations, decelerations, training weeks, sprint distance, and RPE—were taken into consideration while implementing the machine learning algorithms. The future research could explore incorporating technical, tactical, and psychological variables and applying deep learning techniques to potentially further improve the predictive accuracy and practical utility of ML models in the team's sports contexts.

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 Ethics Committee at the University of Trás-os-Montes e Alto Douro (3379-5002PA67807). 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

JT: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. SE: Writing – original draft, Visualization, Formal analysis, Data curation. LB: Writing – review & editing, Validation, Software, Methodology. RF: Writing – review & editing, Resources, Methodology, Conceptualization. DP: Writing – review & editing, Visualization, Validation, Data curation. DM: Writing – review & editing, Formal analysis, Data curation, Conceptualization. RM: Writing – review & editing, Validation, Methodology, Formal analysis. TB: Writing – review & editing, Validation, Resources, Methodology, Conceptualization. AM: Writing – review & editing, Validation, Supervision, Project administration. PF: Writing – review & editing, Supervision, Project administration, 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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Attentional focus modulates physiological response to arousal in a competitive putting task

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Attentional focus during the execution of perceptual motor tasks has been shown to affect performance outcomes. The purpose of this study is to assess the physiological changes prompted by attentional focus in various levels of stress. Thirty-six healthy young males and females were randomized into groups and directed on attentional focus in a staged putting competition scenario intended to elicit competitive anxiety. External focus groups experienced less internal workload at all arousal levels and preserved heart rate variability measures when audiovisual distraction was introduced.

KEYWORDS

motor performance, competitive anxiety, external focus, heart rate variability, audiovisual distraction

1 Introduction

Motor tasks ranging from everyday activities to competitive sports are highly complex processes that are significantly affected by physiological and psychological system dynamics (Mancevska et al., 2016; Mechsner, 2004; Tanaka and Sekiya, 2010). During activities such as sports competition, where situational incentives such as social comparison and rewards for success drive pressure to perform, psychological factors become more influential (Beilock and Gray, 2007; Martens, 1975). Per the processing efficiency theory (Eysenck and Calvo, 1992), performance changes resulting from this pressure to perform are due to the effects of anxiety on the performer's limited attentional capacity. Superior performance requires efficient and effective resource allocation across the entire human operating system (Amico and Schaefer, 2022; Delignières et al., 1994; Englert and Bertrams, 2013). Englert and Bertrams (2013) found that temporarily depleting self-control in a group of participants resulted in a negative relationship between anxiety and perceptual motor performance that wasn't found in the non-manipulated self-control group. Williams, Vickers, and Rodrigues found that performance among table tennis players was diminished while self-reported effort, number of eye fixations, and probe reaction time were all increased in high anxiety conditions (Williams et al., 2002). These changes in fixation and reaction time with increased anxiety exemplify less efficient processing, which the processing efficiency theory points to as a driving factor in performance.

The constrained-action hypothesis states that external focus of attention, or focusing attention on the effects of the intended movement, when conducting a perceptual motor task has been shown to positively affect both learning and overall performance (Wulf et al., 2001b). Furthermore, external focus in skilled performers has been shown to overcome the potentially negative effects of competitive anxiety (Bell and Hardy, 2009). It has been theorized that the benefits of external focus result from encouraging automatic processes of movement to occur, which lessen depletion of attentional resources compared to allowing for optimized learning and performance (Wulf et al., 2001a). While some argue that the constrained-action hypothesis applies solely to skilled performers (Castaneda and Gray, 2007), Munzert et al. (2014) showed that unskilled performers who maintained an external focus displayed more ideal putting kinematics than those maintaining an internal focus.

The lowered processing efficiency observed with increased anxiety can also be observed via measures of cardiac physiology. The autonomic nervous system is responsible for controlling systemic resource allocation in preparation for and recovery from motor performance workloads (Stephenson et al., 2021). This is performed via regulation of the parasympathetic (rest and digest) and sympathetic (fight, flight, or freeze) nervous systems. This interplay causes minute temporal variation in cardiac dynamics, also known as heart rate variability (HRV). For example, assessing the low (0.04 Hz–0.14 Hz) frequency band reflected self-reported mental effort levels, while changes in the high (0.15 Hz–0.4 Hz) frequency band were associated with anxiety-based performance impairment (Mullen et al., 2005). These changes in autonomic tone in response demonstrate the potential to analyze individual measures of HRV to extrapolate an individual's physiological response to a psychological facet: anxiety.

There have not been adequate efforts to explore the physiological effects of competitive anxiety and secondary distractors on externally focused performers. Pelleck and Passmore (2017) utilized surface electromyography (sEMG) during putting with various attentional foci, finding that the skill level of the practitioner and distance of focus from the key elements of the motor skill in question affect the execution of said motor task. Castaneda and Gray (2007) had similar findings, though with both skilled and novice baseball players in a batting simulation. While this clarifies the understanding and optimization of performance on a motor task, the degree to which these same findings occur as arousal increases needs to be investigated.

The objective of this study was to explore the effects of competitive anxiety and distraction stimuli on externally focused performers, which has the potential to provide key insights into resource allocation and attentional focus while performing under anxiety.

We hypothesized that putting performance would be greater in those participants directed to maintain an external focus as opposed to those given no attentional focus, across pressure conditions. We conjectured that increasing attentional demands via competitive stress would be accompanied by a greater increased internal workload, measured via heart rate, in the non-directed attentional focus groups than the external attentional focus groups. We also speculated that the addition of audiovisual distraction, further increasing anxiety, would result in greater internal workloads than their non-distraction group counterparts.

2 Materials and methods

2.1 Participants

Participants were 36 ($n = 22$ males and $n = 14$ females) adults recruited from the local area, aged between 18 and 45 years (Mean = 23.5 years, SD = 5.9 years). Recruitment was performed via campus email, public facing fliers placed at local minigolf and golf courses, social media, and word of mouth. Exclusion criteria for this study consisted of being under the age of 18 or above the age of 65, pregnant, suffering a balance deficiency, have a history of hemiparesis or hemiplegia, or a history of Bell's palsy or other cranial nerve dysfunction. All study procedures were approved by the West Virginia University Institutional Review Board (AAHRPP Accredited). All participants provided their informed consent before participating in any study related activity.

2.2 Equipment

All trials were performed on a level, green AstroTurf running track. An 11 cm (4.33 in) diameter practice putting hole was secured to the track, and a marker of tape indicating the putting position was secured to the track six feet (1.83 m) from the participant facing edge of the putting hole. This distance was found during pilot testing to provide a 30% success rate in self-perceived novice putters, and a 75–85% success rate in self-perceived experienced putters. Two putting irons were provided (an 83.82 cm Odyssey White Steel 2 Ball CS Mallet Putter and an 86.36 cm Spalding Pro Series Ps-2 Blade Putter), though participants were informed that they were allowed to bring their own. Participants were allowed to self-select putting iron, including time to practice with either choice. Standard golf balls were used by all participants.

Shot timing was recorded via the Emerald Timestamp app (Emerald Sequoia LLC). This application utilizes Network Time Protocol to sync with networked computer systems automatically. Heart rate was captured via Polar (Polar Electro) H10 heart rate monitor chest strap connected by Bluetooth to a Polar Grit X watch which was in turn synced via Network Time Protocol before each data collection session. This allowed an accurate comparison of putting time with the heart rate to the nearest second, as the sampling rate of the H10 heart rate monitor when paired with the Polar Grit X watch is 1 kHz. Following manufacturer specifications, participants were instructed to wear the H10 chest strap, with the electrode area of the strap lightly moistened, and centered approximately 3.81 cm below the xiphoid process. The activity mode selected on the Polar Grit X watch for the duration of data collection was "Running."

Neurocognitive tasks, anxiety and workload questionnaires, and trait and experience surveys were all administered via an in-house developed application on a laboratory-provided computer tablet.

2.3 Design

Participants were tested individually over the span of an hour. Acclimation putts were included to control for learning effect. While no maximum putt limit was placed on the acclimation phase, participants were asked to perform at least 15 putts. The mean number of putts before participants indicated readiness to proceed was 21.3 putts. Two testing blocks were performed, during which participants completed three trials of ten putts each (1 trial = 10 putts). The first testing block was the low stress condition, and the second testing block was the high stress condition. In total, the participants completed 30 putts in the low stress condition and 30 putts in the high stress condition.

In the low stress condition trials, participants were informed that the results of these putts did not matter, would not be used for their score in the competition, and were only to ensure that the heart rate monitors were working correctly during putting. During this time the study personnel assumed an intentionally light and supportive manner.

Following completion of the low stress condition trials, participants were briefed about the high stress trials, presented in the form of a faux competition. A falsified leaderboard consisting of five commonly encountered first names and final scores ranging between 10 and 26 was presented to the participant. Tally marks of misses and hits from an imaginary "last participant" were erased from the scoring whiteboard in view of the current participant. The instructions indicated that the total number of successful putts for the next three trials would be tallied, and that the participant had 2 min to perform each individual trial. Participants were told their name would be added to the leaderboard and replace one of the prior participants if the score was high enough.

At the completion of each trial, hit and miss tally marks were added to the score board and the participant was verbally judged on their performance. If the performance was less than 40% of putts made, the phrasing was doubtful of the participants' ability to achieve a leaderboard score. If the performance was at least 40% of putts made, the phrasing was a reminder not to "choke."

Upon completion of data collection, participants were informed of the deception involving competition. They were informed that all participant names and scores on the leaderboard were falsified to create competitive anxiety, and that their name would not be made available to any other participants. All debriefing followed a script approved by the Institutional Review Board.

3 Experimental groups

Participants were randomly distributed between four groups, resulting in n = 9 for each group. These groups consisted of a nondirected focus without distraction group, an external focus without distraction group, a nondirected focus with audiovisual distraction, and an external focus with audiovisual distraction group. The non-directed focus groups were given no instruction on attentional focus, while the external focus groups were instructed to focus their attention on the desired outcome of the movement: the golf ball going into the hole. These instructions were repeated before the onset of each trial in both conditions.

During the high stress condition trials, the non-distraction groups were not subjected to audiovisual distraction, while the non-directed focus/distraction and the external focus/distraction groups were exposed to approximately 75 dBA crowd noise played from a Bluetooth speaker positioned facing the participant and visual distraction in the form of study personnel waving a white beach towel through the air directly behind the target hole. A breakdown of group demographics can be found in Table 1.

4 Measures

4.1 Performance

Performance was measured via the binary outcome of each putt, recorded by study personnel. Participants were not informed that performance was being assessed in the low stress condition but were aware in the high stress condition.

4.2 Competitive state anxiety

Before each trial, the participants engaged in the Competitive Stress Anxiety Inventory-2 Revised (CSAI-2R), a sport specific 17-question inventory which has been shown to be a reliable and valid measure of three facets of competitive stress: cognitive anxiety, somatic anxiety, and self-confidence (Cox et al., 2003). Alpha reliability coefficients range from 0.70 to 0.90 (Martens et al., 1990). Participants rated their current anxiety on a Likert scale ranging from one (*not at all*) to four (*very much so*).

4.3 Cardiac variables

After completion of the informed consent process, participants were supervised in the proper donning of the Polar H10 heart rate monitor and instructed to lay in a supine position with eyes closed and without talking for a 10-min heart rate baseline with HRV measured the last 5 min of resting. Heart rate and interbeat interval (IBI), or the time between subsequent heartbeats, were measured throughout the entire data collection process. Pre-trial HRV epochs consisted of 60 s beginning after the completion of the CSAI-2R and ending with the start of each trial.

Cleaning and analysis of IBI data from the Polar H10 heart rate monitor was performed via Kubios, a validated and widely utilized research tool for the calculation of heart rate variability variables (Kubios HRV program, Biosignal Analysis and Medical Imaging Group, University of Kuopio, Finland). For this effort, focus was placed on root mean square of successive differences (RMSSD), which is generally utilized to estimate parasympathetic activity (Dong, 2016; Stephenson et al., 2021). Specifically, HRVRMSSD was calculated as the change from resting baseline to pre-trial RMSSD.

4.4 Perceived effort

At completion of each trial, participants completed the NASA Task Load Index (NASA-TLX), which weighs six subscales based on participant evaluation of contribution to workload and creates an overall perceived workload score (Hart and Staveland, 1988). The NASA-TLX is a widely used measure with alpha reliability coefficient greater than 0.80 (Xiao et al., 2005). Participants rated each subscale on a Likert scale ranging from one (*low*) to twenty (*high*).

TABLE 1 Group demographic information.

Group	Attentional focus	Distraction status	Sex	Mean age	Experience (Years)
1	Nondirected	Nondistract	3 F, 6 M	23	4.2
2	External	Nondistract	3 F, 6 M	27	10.4
3	Nondirected	Distract	3 F, 6 M	23.3	9.1
4	External	Distract	6 F, 3 M	20.7	8.1

5 Results

5.1 Statistical analysis

All analyses were carried out with R version 4.3.2 (the R foundation for Statistical Computing, Vienna, Austria). For analysis of the low stress condition, where no audiovisual distraction was present, the four groups were combined into two groups of 18 participants: nondirected focus and external focus. Welch's t-test was then applied for anxiety, performance, cardiac variables, and perceived workload in the low stress condition. The introduction of audiovisual distraction in the high stress condition led to the use of a two factor ANOVA based on presence of audiovisual distraction and attentional focus.

5.2 Manipulation check

To evaluate the efficacy of the arousal manipulation, both heart rate and competitive anxiety scores for all groups combined were compared between the low stress and high stress conditions via Welch's t-test. Mean heart rate in the low stress condition was 44.95 bpm and rose in the high stress condition to 50.74 bpm ($p = 0.0005$). For cognitive anxiety, mean scores rose from 7.82 to 9.02 in the low stress and high stress conditions, respectively ($p = 0.0046$). Taken together, this indicates that the competitive pressure manipulation was effective.

5.3 Arousal condition

A significant main effect for stress condition confirmed that for all groups combined cognitive and somatic anxiety levels, as well as change in heart rate from resting baseline, increased between the low stress and high stress conditions (Figure 1). Mean (±SD) values for change in heart rate and heart rate variability from baseline, cognitive and somatic anxiety, self-confidence, and perceived workload for both low stress and high stress conditions are shown in Table 2. Summary statistics for anxiety, performance, cardiac variables, and perceived workload in the high stress condition can be found in Table 3. Putting performance was significantly affected by the addition of competitive pressure, increasing from a mean trial score of 4.57 in the low stress group and 5.19 in the high stress group ($p = 0.023$). This may be misleading, however, as only one of the four groups: the no attentional focus, no distraction group, was significantly different when comparing intragroup low-pressure scores (mean = 4.81) to high-pressure scores (mean = 6.44, $p = 0.0055$). The three other groups showed no difference in score between arousal conditions.

5.4 Attentional focus

Mean (±SD) values for change in heart rate and heart rate variability from baseline, cognitive and somatic anxiety, self-confidence, and perceived workload for both non-directed and external attentional focus are shown in Table 4. As is visible in Figure 2, increase in heart rate from baseline was significantly lower in the external attentional focus groups in both the low stress and competition arousal conditions. While absolute change from baseline in RMSSD was greater, cognitive and somatic anxiety were significantly lower in external attentional focus groups than non-focus directed groups. Perceived workload was also significantly lower in the external attentional focus groups for both arousal conditions, which can be seen in Figure 3.

5.5 Audiovisual distraction

As the distraction manipulation was not present in the low stress condition, only data from the high stress condition are

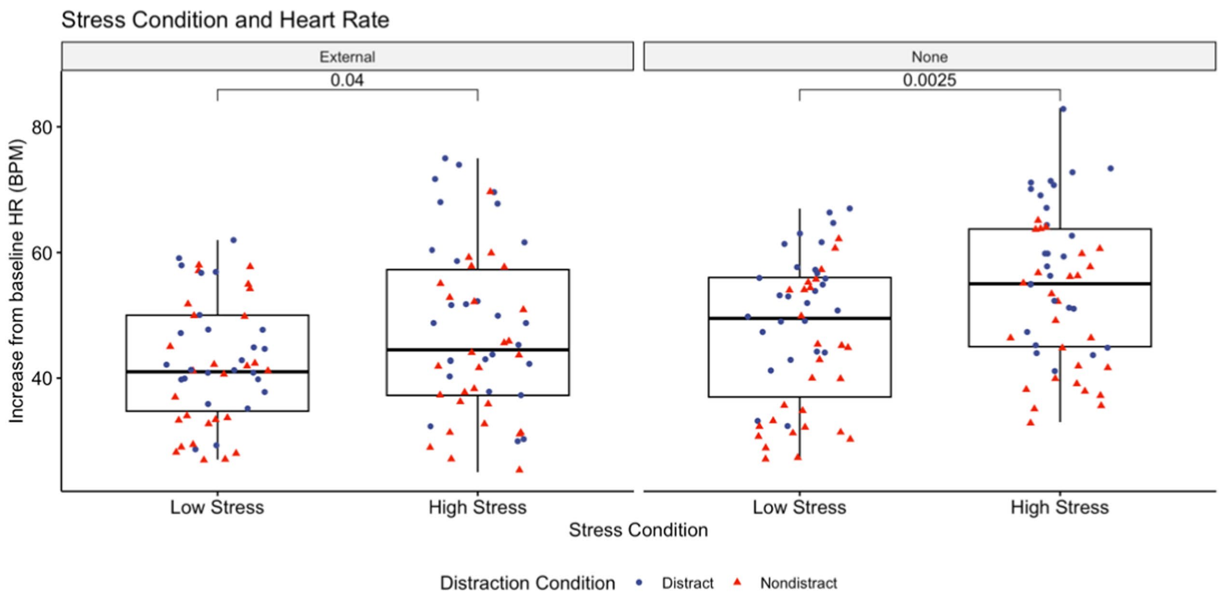

FIGURE 1
Demonstrates the rise in internal workload, measured via heart rate, with the addition of competitive anxiety among both attentional focus conditions. Cohen's D for this comparison in the external focus and non-directed focus groups were −0.404 (small) and −0.597 (moderate), respectively.

TABLE 2 Means (±SD) for anxiety, performance, cardiac, and workload variables.

Variable	Distraction status	Low stress condition		High stress condition	
		Attentional focus		Attentional focus	
		None	External	None	External
Score	Distract	4.59 (2.02)	4.15 (1.66)	4.64 (1.75)	4.78 (1.45)
	Nondistract	4.82 (2.15)	4.74 (2.28)	6.58 (1.70)	4.89 (2.24)
Cognitive anxiety	Distract	8.0 (2.50)	8.04 (3.09)	8.4 (2.78)	10.2 (4.06)
	Nondistract	8.93 (2.53)	6.33 (1.82)	10.1 (2.64)	7.41 (3.08)
Somatic anxiety	Distract	8.33 (1.84)	8.0 (1.30)	10.6 (3.45)	10.4 (2.68)
	Nondistract	12.7 (4.09)	8.93 (2.22)	14.1 (3.55)	9.85 (3.36)
Self-confidence	Distract	15.1 (3.24)	13.4 (2.57)	15.6 (5.06)	12.3 (2.70)
	Nondistract	13.4 (3.56)	12.8 (3.25)	14.3 (3.66)	13.3 (4.34)
Perceived workload	Distract	16.4 (4.58)	12.7 (4.83)	19.3 (4.93)	14.7 (6.68)
	Nondistract	17.3 (6.86)	14.1 (4.86)	24.2 (8.97)	16.5 (4.02)
Heart rate	Distract	52.5 (9.11)	44.5 (8.84)	59.2 (11.2)	51.1 (13.7)
	Nondistract	42.0 (11.4)	40.7 (10.4)	49.3 (10.4)	43.4 (11.8)

TABLE 3 ANOVA summaries for all variables in high stress condition.

Variable	High stress condition		
	df	F	η^2
Score			
Focus	1, 104	5.040*	0.042
Stimuli	1, 104	7.962**	0.066
Focus x Stimuli	1, 104	6.660*	0.055
Cognitive anxiety			
Focus	1, 104	0.052	0.000
Stimuli	1, 104	0.965	0.008
Focus x Stimuli	1, 104	15.716***	0.133
Somatic anxiety			
Focus	1, 104	12.308***	0.096
Stimuli	1, 104	5.090*	0.04
Focus x Stimuli	1, 104	9.968**	0.078
Self-confidence			
Focus	1, 104	7.348**	0.066
Stimuli	1, 104	0.014	0.000
Focus x Stimuli	1, 104	2.352	0.021
Perceived workload			
Focus	1, 104	24.320***	0.182
Stimuli	1, 104	6.964**	0.052
Focus x Stimuli	1, 104	1.584	0.012
Heart rate			
Focus	1, 104	9.459**	0.074
Stimuli	1, 104	14.874***	0.116
Focus x Stimuli	1, 104	0.238	0.002
HRVRMSSD			
Focus	1, 104	8.037**	0.071
Stimuli	1, 104	1.696	0.015
Focus x Stimuli	1, 104	0.012	0.000

*Significant at $p < 0.05$; **significant at $p < 0.001$; ***significant at $p < 0.0001$.

TABLE 4 Means(±SD) for all variables for non-directed and external attentional focus.

Variable	Attentional focus	Stress condition	
		Low stress	High stress
Score	External	4.44 (2.00)	4.83 (1.87)
	None	4.70 (2.07)	5.63 (1.97)
Cognitive anxiety	External	7.18 (2.66)	8.80 (3.83)
	None	8.46 (2.53)	9.26 (2.81)
Somatic anxiety	External	8.46 (1.86)	10.1 (3.02)
	None	10.5 (3.82)	12.4 (3.90)
Self-confidence	External	13.1 (2.92)	12.8 (3.62)
	None	14.3 (3.48)	14.9 (4.41)
Perceived workload	External	12.8 (2.86)	13.0 (3.30)
	None	14.7 (4.06)	15.0 (4.02)
Heart rate	External	42.5 (9.78)	47.2 (13.2)
	None	47.2 (11.5)	54.2 (11.8)
RMSSD	External	31.5 (33.6)	30.9 (33.5)
	None	17.2 (16.9)	16.3 (18.0)

being utilized for these comparisons. Mean (±SD) values for change in heart rate and heart rate variability from baseline, cognitive and somatic anxiety, self-confidence, and perceived workload for both non-distracted and audiovisual distraction conditions are shown in Table 5. Putting performance was significantly better in the non-distracted condition than in those experiencing audiovisual distraction, indicating a successful manipulation. Also of note, change in baseline from RMSSD was significantly greater for participants undergoing an audiovisual distraction than for those with no distraction, but only in those participants who were not directed on attentional focus. Those who were instructed to maintain an external attentional focus showed no difference between presence or lack of audiovisual distraction (Figure 4).

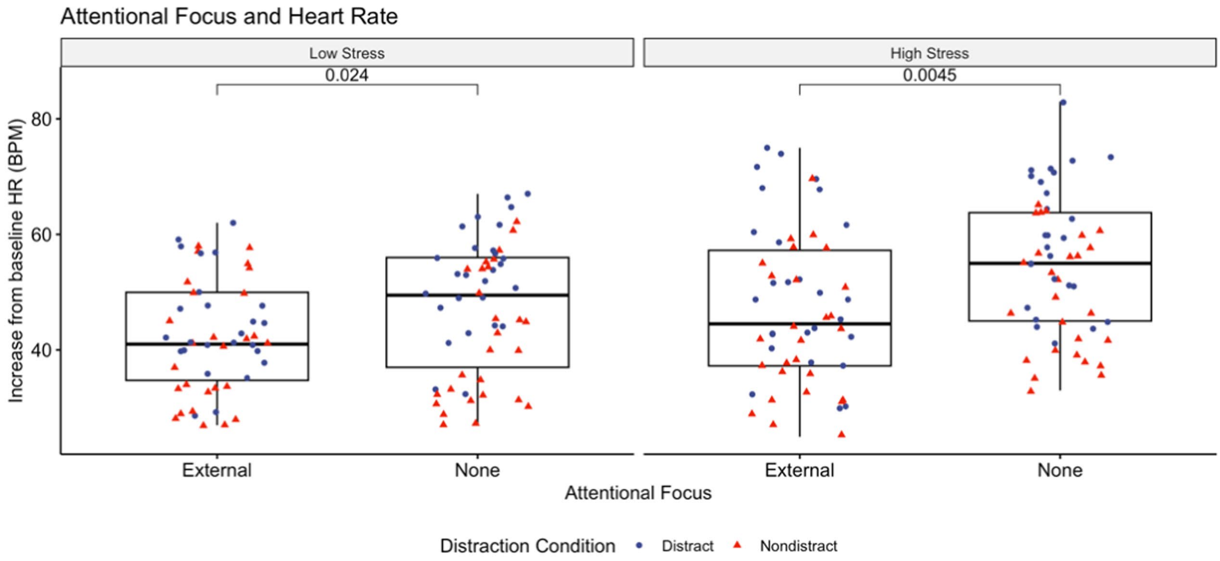

FIGURE 2
Demonstrates the difference in internal workload, measured via heart rate, for both attentional focus conditions at both competitive stress levels. At a higher level of competitive stress, the participants who maintained an external focal point had smaller increases from baseline. Cohen's D for this comparison in the low stress and high stress conditions were −0.444 (small) and −0.558 (moderate), respectively.

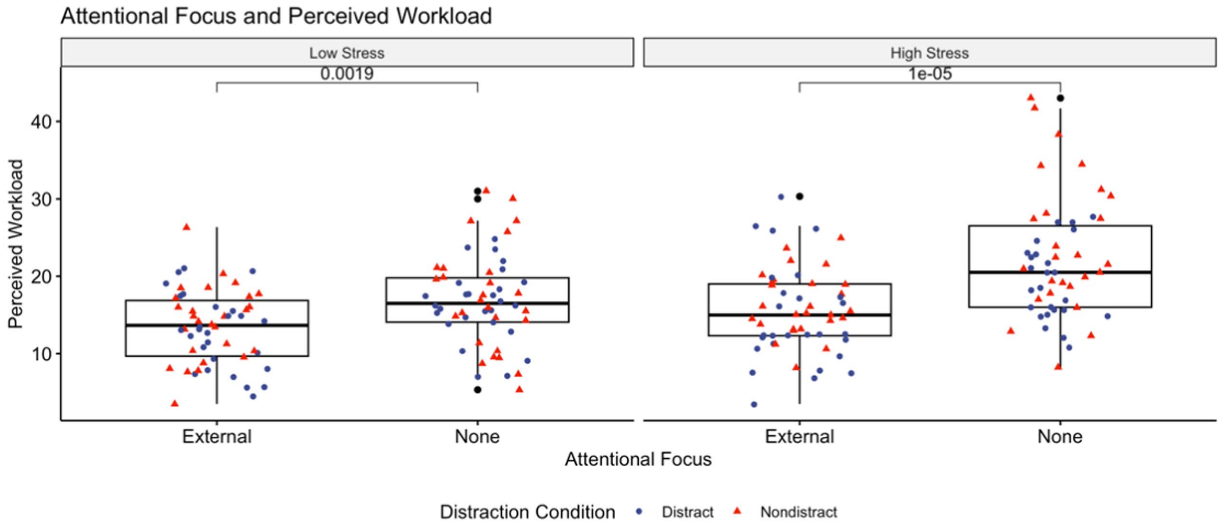

FIGURE 3
Demonstrates the difference in perceived workload, measured via NASA-TLX, for both attentional focus conditions at both competitive stress levels. At a higher level of competitive stress, the participants who maintained an external focal point had operated with lower perceived effort. Cohen's D for this comparison in the low stress and high stress conditions were −0.642 (moderate) and −0.929 (large), respectively.

6 Discussion

The first hypothesis, that putting performance would be greater with the increase in arousal in those groups maintaining an external focus, was not supported by the findings of this study. As noted in the Results section, only one of the four groups had significant differences in score between the low and high stress conditions: the non-directed attentional focus/non-distraction group. We believe that while the competition stages elicited higher internal workloads in both focus groups, represented by an increase in average heart rates, the demands of the task were not high enough to deplete available cognitive resources and allow for observation of performance changes. Additionally, preservation of performance may have been achieved via increases in effort, supported by increased internal and perceived workloads with increased arousal (Eysenck et al., 2007). It is also possible that our mostly novice participants would have benefited from a more proximal attentional focus than the ball going into the hole, for example focusing on causing the ball to pass through an imaginary mark one foot away, on the path from the starting location to the golf hole (Wulf and Su, 2007).

The second hypothesis, that internal workload demands would be greater in the non-focus directed group than the external focus group, was upheld by the data. Change in heart rate from baseline was significantly higher in the non-directed focus group than in the external focus group in both arousal conditions of the study. In addition, score was not significantly different between focus groups in either of the arousal conditions. This indicates a compensatory increase in internal workload to achieve the same performance, regardless of arousal condition, due to attentional focus. This, combined with higher perceived workload in non-directed focus groups lends support to Wulf's constrained action hypothesis (Wulf et al., 2001a).

As predicted, the inclusion of audiovisual distraction resulted in a significant difference in change in heart rate from baseline in the high stress condition. This speaks to the spread allocation of resources required in the presence of task distraction, regardless of attentional focus. Of note was the lack of change, or "rescue," of parasympathetic tone seen with the addition of audiovisual distraction in the external focus group. While both the non-directed and external attentional focus groups saw decreases in vagal tone from baseline, only the non-directed attention focus group had significant difference in vagal tones, with those experiencing audiovisual distraction more affected than those experiencing no distraction. The presence of said preservation may indicate that an external attentional focus has a mitigating effect on arousal while performing a motor task (Figure 4).

A major limitation of this study was the equal task design. Further investigation utilizing skill-based task demands, such as larger or smaller holes depending upon participant performance during the orientation stage, could possibly elicit the performance declines that were originally hypothesized. To make the task accessible for the potential participant base, pilot testing resulted in a less difficult putting task than originally planned (e.g., 10-foot distance). Additionally, the use of a short questionnaire to identify the participants' attentional focus, whether internal or external, after each stage of putting could have resulted in more accurate comparison groups. This could alleviate concerns that some members of the non-focus directed group may have utilized an external focus, though prior research does show that non-focus directed groups consistently produce identical results to internal focus directed groups (Wulf and Su, 2007). The homogeneous nature of age in our study population could possibly be seen as a limitation, but because this work was not meant to investigate the effects of age

TABLE 5 Means (±SD) for all variables for non-distraction and audiovisual distraction.

Variable	Distraction status	Stress condition	
		Low stress	High stress
Score	Distract	4.37 (1.85)	4.72 (1.57)
	Nondistract	4.78 (2.19)	5.67 (2.16)
Cognitive anxiety	Distract	8.14 (2.77)	8.87 (3.30)
	Nondistract	8.43 (2.80)	8.79 (2.94)
Somatic anxiety	Distract	8.92 (2.58)	9.73 (2.87)
	Nondistract	11.9 (3.99)	12.2 (4.04)
Self-confidence	Distract	14.7 (3.81)	14.3 (4.0)
	Nondistract	13.5 (3.5)	13.7 (3.84)
Perceived workload	Distract	13.6 (3.05)	13.7 (3.80)
	Nondistract	13.2 (3.71)	13.4 (3.78)
Heart rate	Distract	52.3 (11.4)	54.3 (11.9)
	Nondistract	44.0 (11.3)	44.9 (11.5)
RMSSD	Distract	25.2 (25.5)	25.2 (25.1)
	Nondistract	18.1 (24.0)	17.7 (24.0)

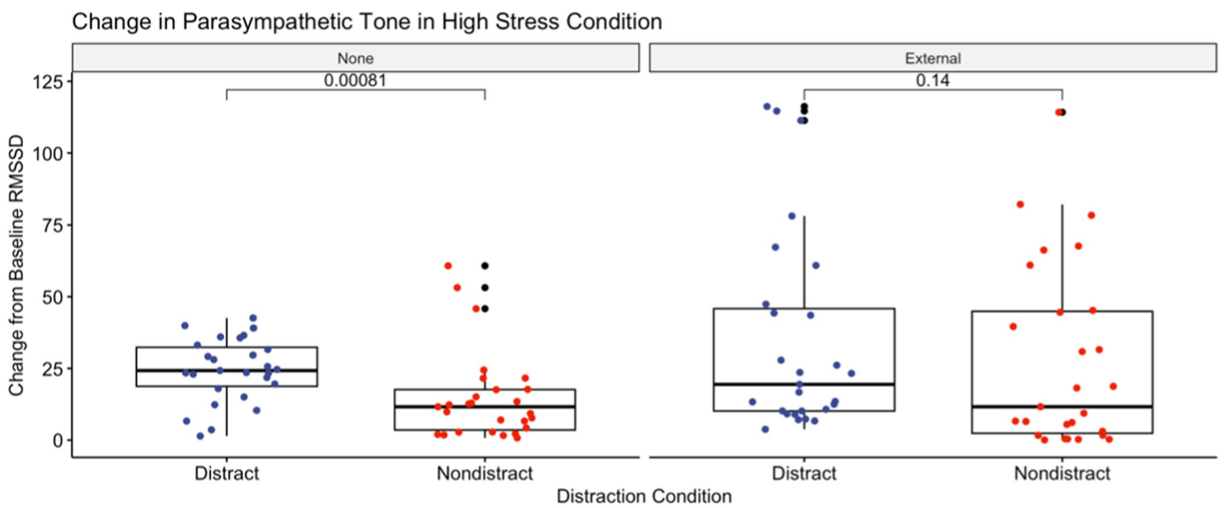

FIGURE 4
Demonstrates the difference in parasympathetic tone, measured via the RMSSD aspect of heart rate variability, for both attentional focus conditions and distraction conditions in the high competitive anxiety condition. Greater change from baseline RMSSD indicates a greater withdrawal of vagal tone. There was no significant difference in change from baseline RMSSD between distraction conditions for participants who were coached to maintain an external attentional focus point. This was false for those who were not coached to maintain an external attentional focus, with the distraction group showing a greater loss of parasympathetic tone from baseline. Cohen's D for this comparison was −0.546 (moderate).

on competitive anxiety and motor task performance, the authors feel this is not a hinderance to the goals of the study. An additional weakness is the low number of participants, though the number of participants per group is similar to prior studies in the field (Hardy et al., 1996; Mullen et al., 2012).

In conclusion, participants in both attentional focus groups saw no degradation in performance, regardless of arousal condition. In the external attentional focus groups, preservation of performance was achieved while utilizing less physiological resources than in the non-directed attentional focus group, even in the presence of audiovisual distraction. External attentional focus-based strategies may therefore be of use at all skill levels, and for multiple purposes: learning proper motor patterns, coping with competitive anxiety, performing in the presence of distraction, and fatigue management.

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 West Virginia University Institutional Review Board. 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

BR: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. VF: Funding acquisition, Project administration, Resources, 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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Investigation of the relationships between sports anxiety, positive thinking skills, and life satisfaction in male athletes

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Sports anxiety is an important obstacle for athletes' performance, negatively affecting their life satisfaction levels. Positive thinking skills can contribute to overcoming such negative conditions. This study explored the relationships between sport anxiety, positive thinking skills, and life satisfaction in male athletes. A total of 338 male athletes participated voluntarily, using convenience sampling. The study employed a relational survey model, and data were collected through the Sports Anxiety Scale-2, Positive Thinking Skills Scale, and Life Satisfaction Scale. Analyses, including Pearson's correlation, were performed using the JAMOVI program, with mediation analysis verified through bootstrapping. Results indicated a negative correlation between sport anxiety and life satisfaction, and a positive correlation between positive thinking skills and life satisfaction. Moreover, positive thinking skills were found to moderate the relationship between sport anxiety and life satisfaction. These insights underscore the value of developing positive thinking skills to help athletes reduce anxiety and enhance their life satisfaction. Therefore, incorporating strategies to foster these skills in training programs could be crucial for improving athletes' overall wellbeing.

KEYWORDS

athlete, life satisfaction, sport anxiety, sports psychology, positive thinking skill

Introduction

Mental health is a complex concept that must be understood as more than just the absence of mental illness. The World Health Organization (WHO) defines mental health as "a state of wellbeing in which individuals realize their own abilities, can cope with the normal stresses of life, work productively, and contribute to their community" (World Health Organization, 2001). Poor mental health is a risk factor for various diseases (Lombardo et al., 2018), and there is a strong inverse relationship between mental health and life satisfaction (Rissanen et al., 2013; Strine et al., 2009; Fergusson et al., 2015; Rissanen et al., 2011; Bray and Gunnell, 2006; Touburg and Veenhoven, 2015). Thus, life satisfaction emerges as a critical concept in health research. It is especially relevant for athletes, who face challenging life conditions due to factors such as high training loads and pressure to succeed. Life satisfaction has been shown to protect athletes from stress (Chen et al., 2017), yet it is also acknowledged that performance pressure can diminish life satisfaction in athletes (Felton and Jowett, 2015).

Anxiety, which is defined as a negative emotional state triggered by physiological arousal, is positively correlated with numerous adverse conditions and detrimentally affects athletic performance (World Health Organization, 2001; Lombardo et al., 2018). These findings also suggest that anxiety is inversely related to positive psychological states. While previous research has shown an inverse relationship between anxiety and life satisfaction (Ayten and Bakır, 2021; Sanioğlu et al., 2018; Kermen et al., 2016; Mahmoud et al., 2012; Beutel et al., 2010), the ongoing interest in understanding this relationship underscores the importance of further investigation, particularly in athletic populations.

Positive thinking skills have gained prominence in recent years as a key factor in maintaining and enhancing positive psychological states. Positive thinking is a cognitive process that creates hopeful images, develops optimistic ideas, finds positive solutions to problems, makes positive decisions, and produces a bright outlook on life in general, without ignoring realism. The ability to think positively is the ability to move toward a positive focus and interpretation, recognizing both the negative and positive aspects of circumstances. As individual differences in thinking patterns exist, providing evidence on the benefits of positive thinking is essential. Positive thinking serves as a critical source of motivation, enabling individuals to approach life with clarity (McGrath, 2024). Those who effectively employ positive thinking skills tend to face challenges optimistically and maintain control in situations that might otherwise provoke stress and anxiety. They also employ functional coping strategies that enable them to manage problems more effectively. Individuals with high levels of positive thinking report that their lives are progressing well, their goals are being met, and they have sufficient resources to cope (Carver and Scheier, 1998; Cantor et al., 1991). These conditions are often associated with increased effort and, consequently, enhanced performance. Previous studies indicate a linear relationship between positive thinking skills and positive experiences, success, and energy in various activities, as well as an inverse relationship between positive thinking and anxiety and stress (Yang et al., 2020).

While much research has been conducted on anxiety and life satisfaction in general populations, fewer studies have explored the moderating role of positive thinking skills in the context of sports, particularly among male athletes. This study aims to fill this gap by investigating the interplay between these psychological factors. Positive thinking skills are viewed as a key psychological resource that enables individuals to reframe stress-inducing situations and employ more adaptive coping strategies. Drawing on cognitive-behavioral theories, positive thinking skills are expected to act as a moderator, mitigating the negative effects of anxiety on life satisfaction.

Based on these findings, it is hypothesized that the relationship between sports anxiety and life satisfaction is particularly relevant in athletic settings, where overcoming challenging conditions is essential. Sports anxiety is expected to negatively affect life satisfaction, while positive thinking skills may serve as a moderating factor, reducing the negative impact of anxiety. In this context, the study tested a theoretical model in which positive thinking skills were included as a moderating variable in the relationship between sport anxiety and life satisfaction among male athletes. This study concentrated on male athletes to address the specific pressures and psychological challenges they face, such as societal expectations and performance demands, which may differ from those of female athletes. Focusing on this population allowed for a more in-depth exploration of how sports anxiety and positive thinking skills impact life satisfaction in male athletes. While the study is limited by its exclusive focus on males, it provides a crucial foundation for understanding these dynamics in male athletes, laying the groundwork for future research that can include female athletes or examine gender differences more explicitly. The results of this study are expected to contribute to the psychological literature on male athletes. For this reason, the study tested the moderating role of positive thinking skills in the indirect effect of sport anxiety on life satisfaction in male athletes. The hypotheses and theoretical model established in this context are given method section.

Methods

The research design

This research is a correlational study designed to explore a unique theoretical framework investigating the moderating role of positive thinking skills. The model includes three variables: sport anxiety, life satisfaction, and positive thinking skills. Positive thinking skills were treated as a moderating variable in the relationship between sport anxiety and life satisfaction. The hypotheses established in this context are outlined below, and the theoretical model developed and tested in the study is visualized in Figure 1.

> *H1*: Sport anxiety has a negative relationship with life satisfaction.
>
> *H2*: There is a positive relationship between positive thinking skills and life satisfaction.
>
> *H3*: There is a negative relationship between positive thinking skills and sports anxiety.
>
> *H4*: Positive thinking skills have a moderating role in the relationship between sport anxiety and life satisfaction.

Participants

There is no consensus on the ideal number of participants required for statistical modeling. In general, a sample size of fewer than 100 is considered small, while a sample size of more than 200 is regarded as large (Bentler and Chou, 1987). Another approach considers the number of variables, where it is accepted that, for normally distributed data, a sample size at least 5 times the number of latent variables is sufficient (Kline, 2005). Based on this, 338 athletes were included in the study. The data used in the study were obtained from 338 male athletes with an average age of 22.5 ± 3.51, who constituted the study group voluntarily based on the convenience sampling method. It was determined that the sports age of male athletes in different branches (athletics, badminton, basketball, gymnastics, fitness, football, tennis, volleyball, swimming, and martial arts) was 7.47 ± 3.53.

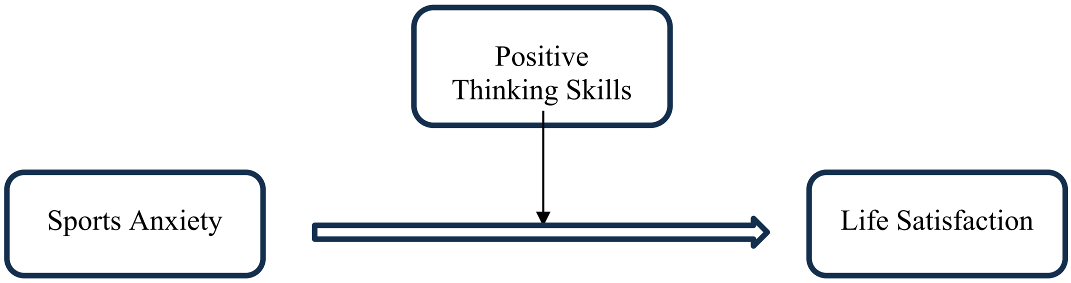

FIGURE 1
The theoretical model established within the scope of the research.

Research ethics

This research was conducted in accordance with the decision of Ankara Yildirim Beyazit University Ethics Committee was carried out in accordance with the authorization. In addition, the Helsinki Declaration was taken into consideration in the whole research process.

Data collection tools

The data used in the study were collected through the Personal Information Form, Sports Anxiety Scale-2, Positive Thinking Skills Scale, and Life Satisfaction Scale. Sport Anxiety Scale-2 was developed by Smith et al. (2006) and adapted into Turkish by Karadağ and Aşçı (2020). The scale consists of 15 questions and has a 4-point Likert type. It has 4 subscales named as somatic anxiety, anxiety, and concentration. The Cronbach's alpha coefficient of the Turkish version of the scale was determined as 0.89. Positive Thinking Skills Scale was developed by Bekhet and Zauszniewski (2013) and adapted into Turkish by Akın et al. (2015). The scale consists of 8 questions and has a 4-point Likert type. The Cronbach's alpha coefficient of the Turkish version of the scale was determined as 0.90. Satisfaction with Life Scale was developed by Diener et al. (1985) and adapted into Turkish by Dağlı and Baysal (2016). The scale consists of 5 questions and is a 7-point Likert-type scale. The Cronbach's alpha coefficient of the Turkish version of the scale was determined as 0.80. Some descriptive information of the male athletes constituting the study group of the research is given in Table 1.

Data collection

The data used in this study were voluntarily provided by the athletes after the research was introduced to them. Before participating, the athletes were thoroughly informed about the study's purpose and scope. They were also told that they could withdraw from the study at any time without providing a reason. Additionally, they were assured that their responses would remain confidential and would not be shared with anyone outside the research team. The results would be reported solely within the context of this study, without disclosing any personal information. Athletes who consented to participate were then asked to complete the measurement tools.

Statistical analysis

In this study, internal consistency was assessed using Cronbach's Alpha coefficient, and reliability was evaluated according to DeVellis and Thorpe's guidelines (DeVellis and Thorpe, 2021), ensuring that all items measured the same construct. Data distribution was examined through skewness, kurtosis values, and visual graphs. Based on George and Mallery's criteria (George and Mallery, 2010), the data showed a normal distribution, justifying the use of parametric tests in the analysis (Table 1).

Pearson correlation coefficients were calculated to test Hypothesis 1, which examined the relationships between the main variables. According to Cohen's guidelines, correlations were classified as small ($r = 0.10–0.29$), medium ($r = 0.30–0.49$), and large ($r \geq 0.50$) (DeVellis and Thorpe, 2021), providing a clearer understanding of the strength of these relationships. To test Hypothesis 2, the JAMOVI medmod bootstrap estimation method (5.000 samples) was employed to assess the moderating role of positive thinking skills in the relationship between sports anxiety and life satisfaction. Moderation effects were considered significant when the bootstrap confidence intervals (CI) did not include zero, indicating a meaningful moderating influence. All analyses were conducted using JAMOVI (version 2.5.2.0), with a significance level set at $p < 0.05$.

Results

Descriptive statistics

Table 1 presents the descriptive statistics derived from the study's data. The Cronbach's Alpha values for all scales were above 0.86,

TABLE 1 Construct validity and reliability results.

	Sport anxiety	Positive thinking skills	Life satisfaction
Minimum	15	7	7
Maximum	39	24	25
Mean	26.7	14.6	16.7
Standard deviation	5.71	4.59	5.43
Skewness	−0.132	0.130	−0.409
Kurtosis	−0.397	−0.393	−1.15
Cronbach's α	0.868	0.905	0.946
McDonald's ω	0.879	0.911	0.949

indicating a high level of reliability in the responses (Diener et al., 1985). Additionally, skewness and kurtosis values fell within the acceptable range of ±1.5, suggesting that the data adhered to a normal distribution. When examining the participants' mean scores across the scales, it can be inferred that they exhibit average levels in the relevant characteristics.

Correlation analysis results

Table 2 shows the Pearson correlation coefficients calculated to determine the relationships between sports anxiety, positive thinking skills, and life satisfaction. The analysis revealed a weak negative relationship between sports anxiety and positive thinking skills ($r = -0.184$, $p < 0.001$), and a moderate negative relationship between sports anxiety and life satisfaction ($r = -0.439$, $p < 0.001$). Additionally, a moderate positive relationship was found between positive thinking skills and life satisfaction ($r = 0.462$, $p < 0.001$). These results indicate three key relationships. First, there is a negative relationship between sport anxiety and life satisfaction, meaning that as sport anxiety increases, life satisfaction decreases. Second, there is an inverse relationship between positive thinking skills and sport anxiety, suggesting that athletes with higher positive thinking skills tend to experience lower levels of sport anxiety. Third, a positive relationship was found between positive thinking skills and life satisfaction, indicating that as positive thinking skills improve, so does life satisfaction.

Moderation analysis results

Table 3 presents the results of the moderation analysis. When the results were examined, it was determined that sports anxiety, identified as the independent variable, negatively affected life satisfaction, identified as the dependent variable in the model (Est = −0.284, SE = 0.047, $Z = -6.05$, $p < 0.001$). Positive thinking skills, identified as the moderator variable, had a positive effect (Est = 0.514, SE = 0.0551, $Z = 9.44$, $p < 0.001$). Furthermore, the moderating effect of positive thinking skills on the interaction between sports anxiety and life satisfaction was found to be significant (Est = 0.026, SE = 0.0086, $Z = 3.03$, $p = 0.002$).

Table 4 shows the detailed analysis results of the moderating effect. When the results are analyzed, it is seen that positive thinking skills were found to be moderate in the details of the moderating effect (Est = −0.284, $p = <0.001$), low (Est = −0.404, $p < 0.001$) and high (Est = −0.164, $p = 0.011$).

According to the results of simple slope analysis, the effects of the regulator variable were shown in Figure 2.

When Tables 3, 4 and Figure 2 are examined together, the moderation analysis indicates that positive thinking skills significantly moderate the relationship between sport anxiety and life satisfaction. Specifically, athletes with higher positive thinking skills experience a weaker negative impact of sport anxiety on life satisfaction. This suggests that developing positive thinking skills may help mitigate the adverse effects of sport anxiety on life satisfaction.

TABLE 2 Correlation analysis results.

		SA	PTS	LS
Sport Anxiety [SA]	p			
	r			
Positive Thinking Skills [PTS]	p	−0.184**		
	r	<0.001		
Life Satisfaction [LS]	p	−0.439**	0.462**	
	r	<0.001	<0.001	

Discussion

Although numerous studies have explored anxiety and life satisfaction in general populations, there is a lack of research examining the moderating role of positive thinking skills specifically in male athletes. This study was conducted to address this gap in order to alleviate this issue, with the hypotheses that sport anxiety is negatively related to life satisfaction, positive thinking skills are positively related to life satisfaction, and positive thinking skills are negatively related to sport anxiety. Additionally, the study tested a theoretical model in which positive thinking skills serve as a moderator in the relationship between sport anxiety and life satisfaction. The findings of this study provide valuable insights into the relationships between sports anxiety, positive thinking skills, and life satisfaction specifically among male athletes. The results emphasize how sports anxiety negatively impacts life satisfaction, while positive thinking skills act as a protective factor. These findings are consistent with recent literature focusing on male athletes and their psychological wellbeing.

The results first revealed a negative relationship between sports anxiety and life satisfaction (Table 2). With this result, the first hypothesis was confirmed. This finding means that there will be a decrease in life satisfaction with an increase in sport anxiety. Athletes often find it difficult to achieve life satisfaction due to the high physical and mental demands of training and the pressure to succeed. The findings of this study align with previous research indicating a negative correlation between anxiety and life satisfaction (Beutel et al., 2010; Yıldırım and Özgökçe, 2023; Perveen et al., 2023; Surujlal et al., 2013). This suggests that anxiety is not only a performance issue but also a factor that significantly affects broader aspects of wellbeing.

Secondly, the study found a positive relationship between positive thinking skills and life satisfaction (Table 2). With this result, the

TABLE 3 Results of moderation analysis.

	Estimate	SE	95% C.I.		Z	p
			LLCI	ULCI		
Sport Anxiety	−0.284	0.0470	−0.372	−0.186	−6.05	<0.001
Positive Thinking Skills	0.514	0.0551	−0.411	0.628	9.44	<0.001
Life Satisfaction ✻ Positive Thinking Skills	0.026	0.0086	0.0093	0.043	3.03	0.002

SE, standardized estimate; C.I, confidence interval; LLCI, lower confidence interval; ULCI, upper confidence interval.

TABLE 4 Simple slope analysis results showing moderation effects.

	Estimate	SE	95% C.I.		*Z*	*p*
			LLCI	ULCI		
Average	−0.284	0.0476	−0.374	−0.185	−5.96	<0.001
Low (-1SD)	−0.404	0.0590	−0.514	−0.280	−6.84	<0.001
High (+1SD)	−0.164	0.0645	−0.288	−0.034	−2.54	0.011

SE, standardized estimate; C.I, confidence interval; LLCI, lower confidence interval; ULCI, upper confidence interval.

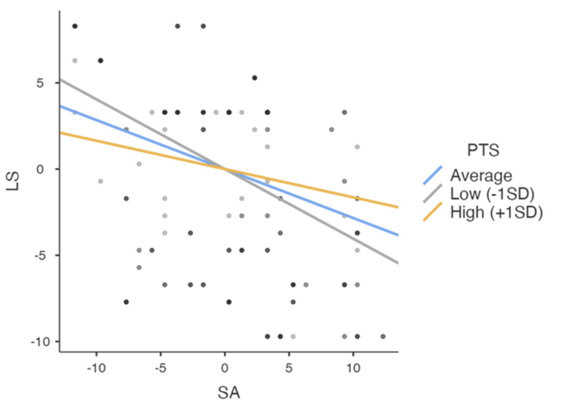

FIGURE 2
Simple slope plot.

second hypothesis was confirmed. This finding means that an increase in positive thinking skills will lead to an increase in life satisfaction. Positive thinking skills can help athletes cope with adversities, thus contributing to higher life satisfaction. This finding is supported by previous research, which similarly identifies a positive association between positive thinking and life satisfaction (Khan and Siddiqui, 2021; Taherkhani et al., 2023; Cohn et al., 2009). The negative relationship between sports anxiety and positive thinking skills further supports the idea that male athletes who engage in positive cognitive strategies experience less anxiety. These results support the cognitive-behavioral approach, which posits that positive thinking can help athletes reframe negative experiences and reduce anxiety.

The study also identified a negative correlation between positive thinking skills and sports anxiety (Table 2). With this result, the third hypothesis was confirmed. This finding means that there will be a decrease in sport anxiety with an increase in positive thinking skills. It is well-established that individuals with greater emotional variability, often associated with negative thinking, tend to experience poorer psychological health (Gruber et al., 2013). In contrast, individuals who possess strong positive thinking skills are more capable of overcoming life challenges by replacing negative thoughts with constructive ones, as supported by prior studies (Yue et al., 2022; Andrade, 2019). The positive correlation between positive thinking skills and life satisfaction underscores the importance of these skills in fostering wellbeing among male athletes. This highlights that positive thinking not only helps mitigate anxiety but also contributes to a more fulfilling life, aligning with the broaden-and-build theory of positive emotions.

Lastly, the findings showed that positive thinking skills have a moderating effect on the relationship between sports anxiety and life satisfaction (Tables 3, 4). With this result, the fourth hypothesis was confirmed. This finding means that the relationship between sport anxiety and life satisfaction can be differentiated by positive thinking skills. In addition to the direct influence of positive thinking on life satisfaction, previous studies suggest that it can also have an indirect effect. For instance, Cohn et al. (2009) provide evidence that positive thinking enhances life satisfaction by fostering resilience. Sanchez and Vazquez (2014) demonstrated that positive emotions can mediate the effect of life satisfaction on attention to positive stimuli, such as happy faces. Similarly, Lightsey and Boyraz (2011) found that positive affect mediates the relationship between positive cognitions and both meaning in life and life satisfaction. The moderation analysis in this study suggests that positive thinking skills significantly weaken the negative impact of sports anxiety on life satisfaction. This is particularly relevant for male athletes who often face high performance pressure. These findings are in line with previous studies, which suggest that individuals with a positive mental framework are more likely to interpret negative events in a favorable light (Zaidel et al., 2021; Xu et al., 2020). This leads to increased life satisfaction, which serves as a vital mechanism for athletes to prevent stress (Chen et al., 2017). This reinforces the notion that psychological resilience, fostered through positive thinking, can be a crucial tool in maintaining life satisfaction despite the challenges of competitive sports.

In conclusion, this study explored the relationships between sport anxiety, positive thinking skills, and life satisfaction in male athletes, addressing a significant gap in the literature. The findings identified three key relationships: a negative correlation between sport anxiety and life satisfaction, an inverse relationship between positive thinking skills and sport anxiety, and a positive correlation between positive thinking skills and life satisfaction. Additionally, positive thinking skills were found to moderate the negative effects of sport anxiety on life satisfaction, emphasizing their protective role.

These results contribute to the growing body of evidence in sports psychology, underscoring the critical role of cognitive strategies such as positive thinking in managing competitive stress. Athletes with higher levels of positive thinking skills experience reduced anxiety and enhanced psychological wellbeing, which in turn improves their life satisfaction. The theoretical model developed in this study suggests that interventions aimed at enhancing these cognitive skills could have practical benefits for reducing sport-related anxiety and promoting overall life satisfaction in athletes. These findings indicate that coaches, sports psychologists, and trainers should implement these strategies to improve athletes' mental resilience and wellbeing.

Limitations

This study has several limitations. The fact that the data were collected exclusively from male athletes limits the generalizability of the findings to the broader athletic population or to female athletes.

As the study employed a cross-sectional design, it was not possible to determine causal relationships between the variables. The reliance on self-report measures introduces the potential for response bias in participants' answers. Additionally, the limited sample size and diversity restrict the generalizability of the results to athletes from different sports and age groups. The use of convenience sampling further limits the representativeness of the sample, making it difficult to generalize the findings to a wider population. The study's specific cultural context also suggests that the findings may not be applicable to athletes in other cultural settings. Furthermore, the absence of any control variables in the analyses is another limitation that should be considered when interpreting the results. Finally, the descriptive nature of the research indicates that the findings should be interpreted with caution, as further in-depth analyses are required.

Conclusion

Theoretical implications

This study enriches our understanding of the effectiveness of positive thinking skills in overcoming sport anxiety. By establishing a clear link between sport anxiety and life satisfaction, it highlights the critical role of positive emotions in promoting life satisfaction among athletes. These findings suggest that overcoming sport anxiety is essential for athletes to achieve life satisfaction. Furthermore, the evidence that positive thinking acts as a moderator in this relationship offers a fresh perspective on how psychological skills can influence wellbeing. The study provides valuable insights that may guide future research in exploring the mechanisms by which positive thinking skills help prevent sport anxiety and enhance life satisfaction. These contributions expand the theoretical framework surrounding sport psychology, emphasizing the importance of psychological resilience and cognitive strategies in maintaining emotional and psychological wellbeing in demanding athletic environments.

Practical implications

This highlights the importance of integrating positive thinking skills into the training and development programs of athletes. This study underlines the benefits of having positive thinking skills to increase life satisfaction levels for athletes and suggests applicable strategies for both athletes and coaches. Athletes should strive to overcome their sport anxiety in order to increase their life satisfaction levels, with the awareness that their life satisfaction levels can affect their performance. Based on the results of the research, it can be said that focusing on positive thinking skills may be useful in this regard. With the same perspective, coaches should create mechanisms to support their athletes in developing positive thinking skills to overcome their sport anxiety.

Coaches and sports psychologists should prioritize training athletes in mental resilience and cognitive strategies that foster positive thinking. In particular, techniques that enhance focus, stress management, and emotional regulation could be essential in reducing sport anxiety and enhancing life satisfaction. Additionally, developing effective anxiety management strategies is critical. Coaches can implement relaxation techniques, mindfulness practices, and cognitive restructuring to help athletes cope with competitive pressure. Regular psychological assessments and monitoring of athletes' wellbeing are also recommended, as this will allow early detection of potential psychological issues. The findings further emphasize the role of positive thinking in not only improving individual performance but also creating a supportive team environment. Lastly, enhancing athletes' overall life satisfaction through programs focused on career development, social support, and personal growth will likely contribute to their long-term psychological health and athletic success.

Future research

Future research should investigate the effects of various factors, such as athletic mental energy, emotional intelligence, and the coach-athlete relationship, on overcoming sport anxiety and improving life satisfaction. Exploring the interplay between these factors and how they influence athletes' mental health and performance can provide valuable insights. Additionally, it would be beneficial to examine the role of social support systems, including family, peers, and sports communities, in mitigating sport anxiety and enhancing life satisfaction among athletes. Longitudinal research is crucial for a more nuanced understanding of these relationships. Such studies would allow researchers to observe changes in sport anxiety and life satisfaction over time, providing a clearer picture of causality. Furthermore, examining diverse populations, including female athletes and those from various sports backgrounds, will contribute to a more comprehensive understanding of the dynamics at play. This can lead to the development of tailored interventions that address specific needs and challenges faced by different athlete groups.

Finally, future studies could also focus on the implementation and effectiveness of training programs designed to enhance positive thinking skills and other psychological resilience factors in athletes. Understanding how these interventions can be integrated into regular training routines may provide practical solutions to enhance athletes' overall wellbeing and performance.

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 Health Sciences Ethics Committee of Ankara Yıldırım Beyazıt 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

ET: Conceptualization, Data curation, Investigation, Methodology, Supervision, Visualization, Writing – original draft, Writing – review & editing. AY: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Visualization, Writing – original draft, Writing – review & editing. IFY: Supervision, Visualization, Writing – review & editing. IY: Conceptualization, Formal analysis, Investigation, Resources, Supervision, Visualization, Writing – original draft, Writing – review & editing. LS: Conceptualization, Funding acquisition, Supervision, Writing – original draft, Writing – review & editing. D-AI: Conceptualization, Funding acquisition, Visualization, Writing – review & editing. OI: Conceptualization, Visualization, 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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Running, walking, and cross-country skiing: how to shape adolescents' personalities through physical activity?

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Adolescence is crucial for personality development, and sports play a significant role. This study investigates the impact of various sports on the personality traits of junior high and high school students in Shandong Province, focusing on neuroticism, extraversion, openness, agreeableness, and conscientiousness. Utilizing data from the "Database of Youth Health," we employed Seemingly Unrelated Regression (SUR) and Generalized Structural Equation Modeling (GSEM) to analyze the effects of physical activity on personality development. Findings reveal that walking significantly enhances openness and decreased neuroticism, while jogging/running substantially improves extraversion, agreeableness, and conscientiousness. Cross-country skiing, however, negatively impacts all assessed personality traits. In addition, the importance of gender differences in the relationship between physical activity and personality development was revealed. The results offer insights for promoting adolescent personality development through targeted sports activities.

KEYWORDS

adolescent personality, sports participation, Big Five Personality Traits, gender differences, physical activity frequency, Seemingly Unrelated Regression Models

1 Introduction

Adolescence is a critical phase of rapid physical and mental development, as well as a crucial period for shaping and developing personality traits (Shiner et al., 2023; Logan and Ward-Ritacco, 2022). During this stage, an individual's personality traits not only have a profound impact on their current psychological health (Donker et al., 2024; Kumar and Vijayakumar, n.d.) but also affect their future career choices (Arslan et al., 2023), interpersonal relationships (Shiner et al., 2023), and life satisfaction (Kang and Malvaso, 2023). Therefore, exploring factors that influence the development of adolescent personality traits holds significant theoretical and practical value, especially those factors that can be altered through personal or societal intervention. Sports activities, as a common recreational activity, are widely believed to have a positive impact on psychological health and personality development (Tahira, 2022; Eather et al., 2023; Zhou et al., 2022; Kumar et al., 2023), hence the role of sports in promoting the positive development of personality traits has received extensive attention.

Existing research on the relationship between sports and personality traits is abundant. Most scholars have found that extraversion, openness, agreeableness, and conscientiousness are positively correlated with physical activity, while neuroticism is negatively correlated with physical activity (Rhodes and Smith, 2006; Jarvis, 2006; Elman and Mckelvie, 2003; Sevcikova et al., 2000; Ledwidge, 1980; Jasnoski et al., 1988; Liao et al., 2022; Allen et al., 2021; Rhodes and Wilson, 2020; Hakulinen and Jokela, 2018). However, some scholars believe that there is no correlation between physical activity and neuroticism (Stephan et al., 2018; Allen et al., 2015; Stephan et al., 2014). Further studies have delved deeper into the relationship between sports and personality traits, exploring the impact of participating in different types of sports on personality traits. For example, Schurr et al. (1977) found that team athletes were more anxious and extroverted than individual athletes; Francis et al. (1998) found that female hockey players, compared to those not formally engaged in sports, had higher levels of extraversion and neuroticism. Breivik (1996) conducted a 16 PF test on 38 elite Norwegian climbers, finding them to have very low neuroticism and higher extraversion and adventurousness; Freixanet (1991) conducted an EPQ test on a group of high-risk sports participants (including 72 mountaineers) and a group of low-risk athletes, finding that mountaineers and other high-risk sports participants had higher extraversion and lower neuroticism levels; Diehm and Armatas (2004) used NEO-PI to compare the personality traits of 44 golfers (low-risk) and 41 surfers (high-risk), finding that surfers had higher openness. Additionally, scholars have also focused on the sports level of participants. Egloff and others, and Williams and others, found that elite athletes were more extroverted and less neurotic than recreational athletes (Egloff and Gruhn, 1996; Williams and Parkin, 1980). Although existing research on personality traits and sports is relatively abundant, there are still three shortcomings that need to be addressed. First, many studies have used older personality scales, such as Cattell's 16PF Personality Scale and the Eysenck Personality Questionnaire, which reduces the applicability of these studies' conclusions in modern sports psychology. Second, few studies have classified sports by discipline and conducted horizontal comparisons between different sports, investigating the impact of participation in various sports on personality traits. In practice, understanding the differences between different sports can help coaches and educators develop more targeted physical activities based on individuals' specific needs and personality development goals. Third, the sample sizes in previous studies have been relatively small (most involving around 100 participants, while this study includes 21,521), which limits the generalizability of their conclusions. In this paper, we conducted an in-depth study on the relationship between physical activity and personality traits, addressing these three shortcomings.

In this research, data derived from the "The Database of Youth Health" were utilized to focus on junior high and high school students across 17 cities in Shandong Province. By analyzing their sports behaviors and personality traits, the aim is to delve deeper into the impact of different sports on the development of adolescents' personality traits and to examine whether gender plays a moderating role in this relationship. The main variables of interest in this study are the five personality traits from the Big Five personality model—neuroticism, extraversion, openness, agreeableness, and conscientiousness—as well as various sports activities participated in by the adolescents, such as jumping rope, roller skating, tag games, and walking exercises. Through the analysis of Seemingly Unrelated Regression Models, this study not only explores the impact of participating in specific sports on personality traits but also assesses the moderating effect of the frequency of sports activities on this relationship. Further, given the significant plasticity of personality traits during adolescence (Belsky, 2013; Schriber and Guyer, 2016)—a critical period for psychosocial development—focusing on this group adds substantial real-world relevance to the study.

Through a systematic analysis of the relationship between adolescent sports behavior and personality traits, this study aims to provide a scientific basis for promoting adolescent personality development through sports. It also aims to offer references for parents, schools, and policymakers in the arrangement of adolescent education and sports activities. Additionally, the results of the study will enrich the theoretical knowledge in the fields of sports psychology and developmental psychology, especially in understanding the mechanisms of how sports influence the development of adolescent personality traits and the aspects of gender differences.

2 Data, variables, and analysis strategy

2.1 Data

This paper utilizes the "The Database of Youth Health" (a cross-sectional dataset) for related empirical research (Zhang et al., 2022). This project conducted multiple rounds of surveys in 2015, 2016, 2017, and 2020 among junior high and high school students in 17 cities of Shandong Province. The survey covered 11 aspects, including personal information, family background, school adaptation, sports behavior, among others (not all 11 aspects were included in every round of the survey). We used Stata software to filter the dataset, retaining only the samples that contained all four aspects (including the variables relevant to our research)—personal information, family background, school adaptation, and sports behavior. This resulted in 23,314 samples. After excluding 1,793 samples that contained missing or anomalous values (those outside the specified range), 21,521 samples were ultimately included in the empirical analysis model. Descriptive statistics of the data and variables are shown in Table 1.

2.2 Variables

2.2.1 Dependent variables

The dependent variables in this paper are the five personality traits from the Big Five personality model: neuroticism, extraversion, openness, agreeableness, and conscientiousness. Based on the definitions and descriptions of these dimensions by multiple scholars (Costa and Mccrae, 1992; John, 1990; John and Srivastava, 1999; Soto and John, n.d.; Saucier and Ostendorf, 1999), the author selected corresponding questions from the "The Database of Youth Health" to measure the development levels of these personality traits among middle school students. Table 2 displays the test items for each personality trait dimension. To further assess the internal consistency of the Big Five Personality Traits Scale, this study conducted a Cronbach's Alpha reliability test on 21 items. The results showed that the Cronbach's alpha coefficient of the scale was 0.907, indicating that the scale has a very high internal consistency. This result suggests that the 21 items selected were able to reliably and consistently measure the Big Five Personality Traits of the subjects. In this study, the test items for openness are scored negatively, meaning that lower scores on openness indicate higher developmental levels of this personality trait.

TABLE 1 Descriptive statistics for key variables.

Variable	Mean	Standard deviation	Minimum	Maximum
Neuroticism	4.302	2.082	3	15
Extraversion	10.214	2.539	3	14
Openness (negative scoring)	3.341	1.367	2	9
Agreeableness	24.360	4.876	7	32
Conscientiousness	21.608	4.533	6	29
Jump rope	2.330	1.348	1	5
Roller skating	1.672	1.158	1	5
Chase and capture game	2.022	1.223	1	5
Walking exercise	3.189	1.399	1	5
Cycling	2.358	1.439	1	5
Jogging or running	2.950	1.233	1	5
Swimming	1.548	1.045	1	5
Baseball, softball	1.437	0.964	1	5
Dance-based movement	1.580	1.072	1	5
Badminton	1.998	1.241	1	5
Skateboarding	1.597	1.089	1	5
Soccer	1.785	1.165	1	5
Volleyball	1.637	1.099	1	5
Basketball	2.014	1.290	1	5
Ice skating	1.463	0.999	1	5
Cross-country skiing	1.373	0.913	1	5
Other	1.891	1.201	1	5

2.2.2 Independent variables

The main independent variables in this paper are the frequencies of participation in different types of sports. The corresponding question in the "Adolescent Health Themes Database" survey is: "How often did you participate in the following sports during leisure time in the past 7 days?" There are 18 categories of sports listed under this question. However, since "aerobic exercises" include activities like cycling and jogging, which could cause multicollinearity issues, aerobic exercises are not included in this study. As shown in Table 1, there are 17 main independent variables in this study, corresponding to the participation frequencies in 17 different types of sports, with values ranging from 1 to 5, where "1" represents none, never done; "2" represents 1–2 times; "3" represents 3–4 times; "4" represents 5–6 times; "5" represents 7 times or more.

2.2.3 Control variables

After reviewing a substantial amount of literature (Sherafati et al., 2020; Imam et al., 2021; Kekäläinen et al., 2020; Markowska et al., 2017; Modestin, 2006; Nakao et al., 2000; Anderson et al., 2024; Milenkova and Nakova, 2023), we selected a number of factors from the database that may influence sports participation (independent variable) and personality development (dependent variable) as control variables. These include gender, place of residence, mother's education level, father's education level, family economic condition, father's occupation, mother's occupation, the frequency of vigorous physical activity during physical education classes in the past 7 days, and family relationships.

2.3 Analysis strategy

The dependent variables in this paper are five in number, and the independent variables used to estimate these five personality traits are identical, which means that any omitted variables not included in the regression will affect all five dependent variables simultaneously. Additionally, there is likely to be a correlation among the five personality traits, and using five separate OLS models for regression would result in inaccurate estimates of the coefficients of the independent variables. Therefore, we choose to use the Seemingly Unrelated Regression (SUR) model for estimation. The SUR model takes into account the correlation among the dependent variables of the five independent models, allowing for joint estimation, which can also improve the estimation bias caused by omitted variables, thereby enhancing the estimation efficiency of the model.

3 Empirical analysis of the impact of participating in different sports on personality traits

3.1 Which sports most significantly enhance adolescent personality development?

In our analysis, we transformed the independent variables representing sports participation frequency into binary variables.

TABLE 2 Big Five personality dimensions test items.

Personality traits	Description and definition	Measurement item
Openness	Ideas; Actions; Feelings; Values (Costa and Mccrae, 1992); Narrow interests; Simple; Shallow (John, 1990); Conservative attitudes (John and Srivastava, 1999)	1. Do you often find life uninteresting? 2. Unwilling to share with other students
Conscientiousness	Order; Dutifulness; Self~Discipline; Competence; Deliberation (Costa and Mccrae, 1992); Organized; Reliable; Painstaking (John, 1990); following norms and rules (John and Srivastava, 1999)	1. Have the ability to be admired by classmates 2. Complete assigned homework or tasks on time 3. Follows classroom discipline 4. The ability to adapt to the demands and expectations of school 5. Have the ability to exercise self-control and self-discipline 6. When faced with a difficult task, can you still keep doing it?
Extraversion	Talkative; Assertive; Outspoken; Dominant; Sociable (John, 1990); number of friends and sex partners (John and Srivastava, 1999); number of friends (John and Srivastava, 1999)	1. Show decisiveness when needed 2. Do you have many good friends? 3. Skillfully interacts with or joins in with classmates 4. Socialize with many peers
Agreeableness	Sympathetic; Kind; Affectionate; Soft-hearted; Generous; Trusting; Helpful (John, 1990); Trust; Altruism; Empathy (Soto and John, n.d.); Emphasize the good qualities of other people when I talk about them (John and Srivastava, 1999)	1. Be able to take the initiative to help classmates 2. Understand the problems and needs of classmates 3. Be able to recognize the psychological changes of other students. 4. Be able to avoid losing my temper when I am angry or furious. 5. Do you think your classmates are friendly to you? 6. Do your friends care about you? 7. Do you think your teachers are friendly to you?
Neuroticism	Moody; Temperamental; Unstable; Emotional (John, 1990); Emotionality; Irritability (Soto and John, n.d.; Saucier and Ostendorf, 1999); Impulsiveness (Costa and Mccrae, 1992)	1. Easily provoked and easily offended 2. Behavior is difficult to control 3. Behaves impulsively without thinking

Here, a frequency of zero times per week was encoded as "0," and any frequency above zero was encoded as "1." This binary recoding was implemented to more straightforwardly assess and compare the marginal effects of different sports on personality traits. This approach simplifies the statistical analysis, allowing clearer interpretations of how even minimal participation in various sports influences personality traits compared to non-participation. In addition, as shown in Figures 1–5, we visualized the results of the data analysis (here the results of the data analysis controlled for control variables) in order to present the results of the study in a more intuitive way.

The analysis conducted using Seemingly Unrelated Regression Models, coupled with the specific criteria of the test items for each personality dimension, identifies optimal sports for personality development. Walking exercise is most effective in reducing neuroticism ($B = -0.482$, $p < 0.001$), while jogging or running excels in fostering extraversion ($B = 0.639$, $p < 0.001$), agreeableness ($B = 1.963$, $p < 0.001$), and conscientiousness ($B = 1.404$, $p < 0.001$). Walking exercise also promotes openness ($B = -0.262$, $p < 0.001$). Figures 1–5 further illustrate that both walking and jogging or running significantly enhance all five personality traits.

Furthermore, as indicated in Table 3, the ranking of the best sports for impacting various personality traits remains consistent, regardless of the inclusion of control variables in the regression analyses. This consistency underscores the robustness of the findings, suggesting that the identified relationships are stable across different model specifications.

3.2 Robustness tests

3.2.1 Addressing changes in model error structure

We used Pearson correlation analysis to test the correlation between the dependent variables in this paper, as shown in Figure 6, and found that there is a high correlation between all five dependent variables studied in this paper, indicating that there is a need to use seemingly unrelated regression (SUR) for joint estimation to improve the efficiency of model estimation.

3.2.2 Modifying the estimation approach

To ensure that the findings of this study are not disproportionately influenced by a specific estimation technique, thereby potentially compromising robustness, the author employed Generalized Structural Equation Modeling (GSEM). This method is adept at elucidating complex interactions between observed and latent variables. Additionally, robust standard errors were computed to refine the accuracy of the parameter estimates. According to the results displayed in Table 4, the outcomes using GSEM align perfectly with those from the Seemingly Unrelated Regression model, with no change in the sports identified as most beneficial for each personality trait. This consistency across different estimation methods reaffirms the robustness of the study's results, demonstrating that the findings are not uniquely tied to any single regression technique.

3.2.3 Modifying data sample segmentation

Given the documented differences in physiology (Burke et al., 2019), societal expectations (Çerimli, 2022; Christen, 2017), and body

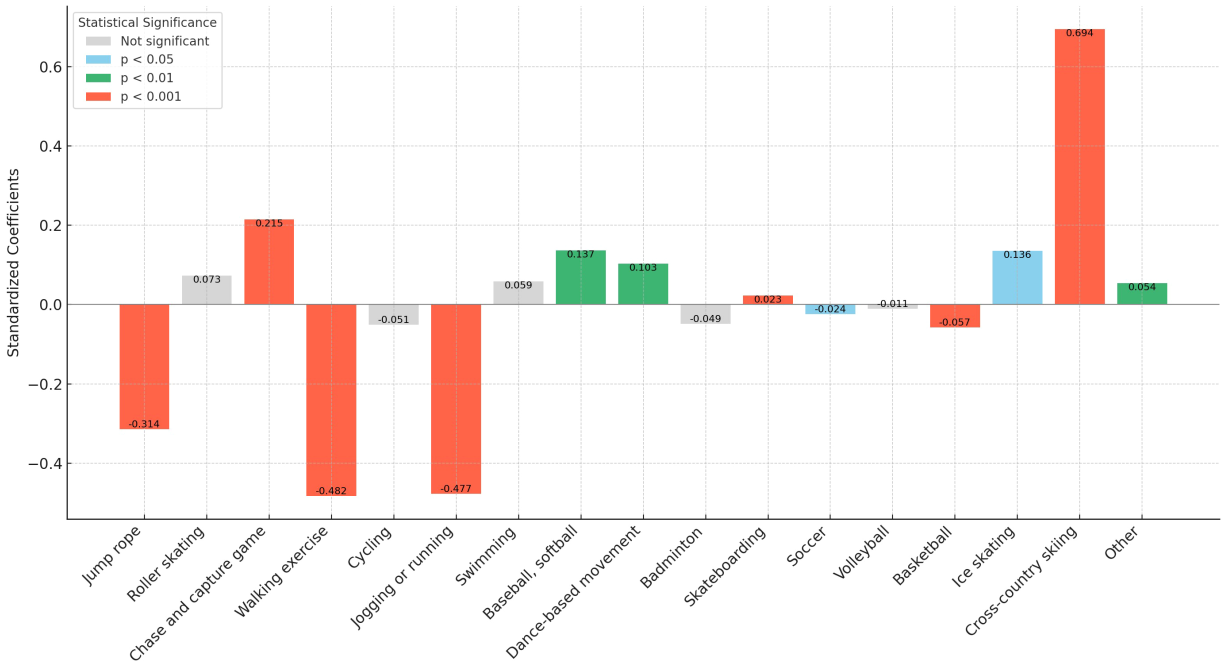

FIGURE 1
Impact of different sports on the neuroticism trait.

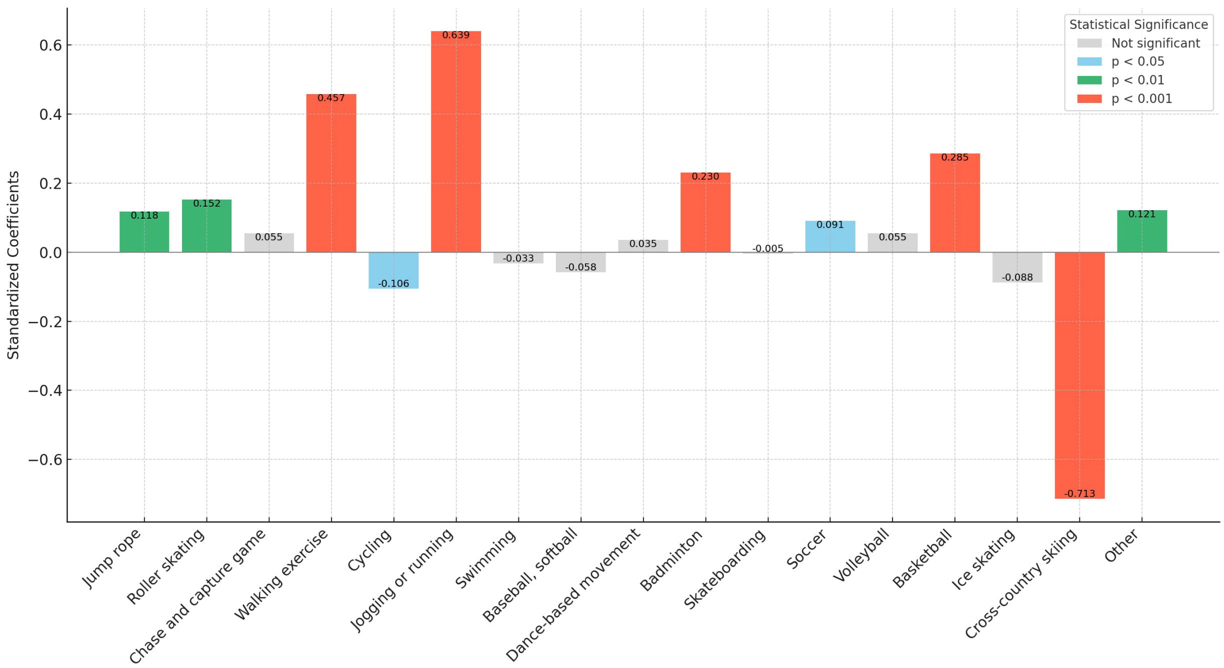

FIGURE 2
Impact of different sports on the extraversion trait.

perception between genders (Picone et al., 2022; Breda-Vicentini et al., 2020), it is anticipated that the relationship between sports participation and personality traits might vary by gender. Consequently, it is essential to stratify the study's sample into male and female groups to conduct distinct analyses. This approach will enable a more detailed examination of how participation in various sports affects personality traits differently across genders.

As delineated in Figures 7, 9, the sample was categorized by gender for targeted regression analyses. The findings indicated no gender disparity in the optimal sports for enhancing extraversion and

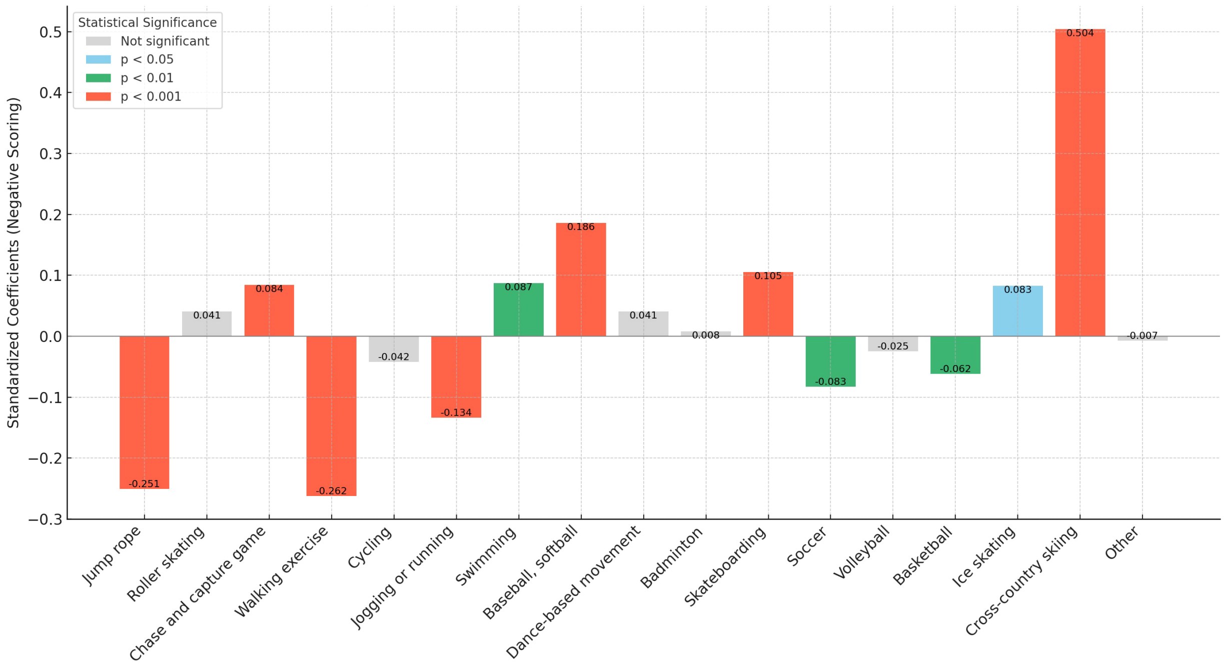

FIGURE 3
Impact of different sports on the openness trait.

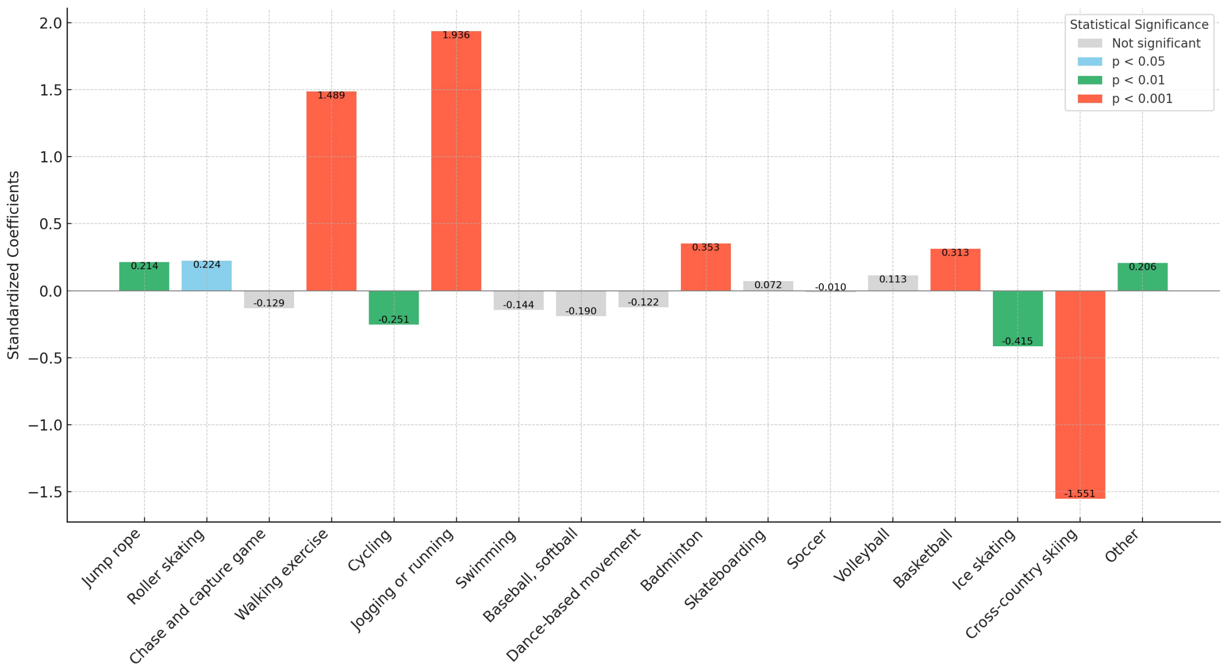

FIGURE 4
Impact of different sports on the agreeableness trait.

openness, with jogging or running and walking exercise proving most beneficial, respectively.

However, significant gender-specific differences were observed in the optimal sports for neuroticism, agreeableness, and conscientiousness, as detailed in Figures 8, 10, 11. For males, jogging or running is most effective in reducing neuroticism ($B = -0.602$, $p < 0.001$) and enhancing agreeableness ($B = 2.196$, $p < 0.001$) and conscientiousness ($B = 1.665$, $p < 0.001$). For females, walking exercise yields the best results in lowering neuroticism ($B = -0.454$, $p < 0.001$), improving agreeableness ($B = 1.724$, $p < 0.001$), and boosting conscientiousness ($B = 1.258$, $p < 0.001$). These outcomes underscore the importance of considering gender when recommending sports activities for personality development.

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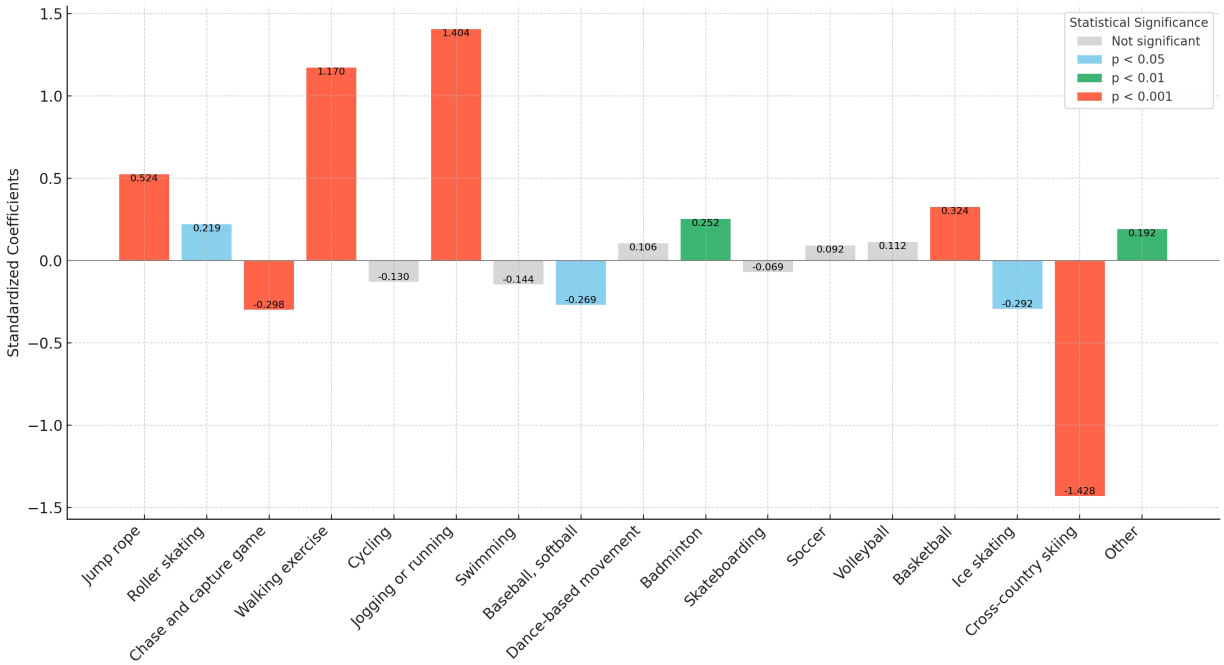

FIGURE 5
Impact of different sports on the conscientiousness trait.

4 Discussion

4.1 Outstanding performance in walking exercises and jogging or running

Significant variations exist in how different sports affect personality traits, with walking and jogging or running notably effective in fostering such traits. Specifically, jogging or running greatly improves extraversion, agreeableness, and conscientiousness. In contrast, walking is particularly effective at mitigating neuroticism and boosting openness. These outcomes can be interpreted through several psychological lenses. Firstly, these activities enhance self-efficacy as participants can concretely measure their progress, boosting confidence in their capabilities and thereby their self-efficacy (Vassell, 2023). Increased self-efficacy encourages greater social interaction, which enhances extraversion (Esfandagheh et al., 2012). Secondly, these sports involve setting precise, achievable goals (Consolo, 2007). Achieving these goals not only improves organizational and persistence skills, fostering conscientiousness (Weinberg and Butt, 2014), but also enhances self-esteem and positive self-perception, indirectly promoting extraversion and agreeableness (Cetinkalp, 2012; Extremera et al., 2016; Lochbaum et al., 2016). Additionally, the interaction between physical activity and personality traits suggests that certain traits might predispose individuals to prefer certain sports (Kuper et al., 2023), which in turn might amplify those traits. For instance, extroverts may gravitate toward group sports like jogging clubs, which can further augment their extraversion (Asquith et al., 2022). This dynamic illustrates the complex interplay between personality and physical activity, highlighting how specific physical activity can differentially impact personality development.

From a physiological standpoint, the distinct impacts of walking exercises and jogging or running can be attributed to several factors: Firstly, endorphins and emotional regulation. These aerobic activities are known to enhance the release of endorphins (Kpame and Richard, 2020), neurotransmitters linked to improved mood and increased pleasure, which can significantly alleviate pain and enhance emotional well-being (Niikura et al., 2008; Jensen et al., 2017; Pilozzi et al., 2020). This boost in endorphins can lead to reduced stress and anxiety, thereby fostering positive personality development (Khoury and Nagy, 2023; Ye and Liu, 2023). Secondly, brain structure and function alterations. Regular aerobic exercise is beneficial for the growth of brain areas crucial for emotional regulation and cognitive function, notably the hippocampus and prefrontal cortex (Manning and Steffens, 2018). These adaptations can stabilize emotions and decrease neurotic tendencies. Thirdly, improved circulation and oxygenation. Activities like walking and jogging enhance cardiopulmonary efficiency, which boosts cerebral blood flow and nutrient delivery. This, in turn, supports neuronal health, crucial for enhancing traits such as openness, associated with creativity and novel experiences (Leasure and West, 2016). Fourthly, sleep quality enhancement. Consistent physical activity, such as walking and jogging, has been shown to improve sleep quality (Xu et al., 2023; Kline, 2014), a vital component for maintaining emotional balance and cognitive clarity, which indirectly supports the development of positive personality traits like conscientiousness and lowers neuroticism (Bender and Lambing, 2024; Semplonius and Willoughby, 2018). Fifthly, stress management. These exercises reduce stress reactions, lower cortisol levels, and bolster stress resilience (Ilmi et al., 2022; Ibrahim et al., 2020), contributing to increased conscientiousness and agreeableness and decreased neuroticism (Kaiseler et al., 2012; Mccrae, 1990).

From an evolutionary psychology perspective, walking and running were essential for survival in early human societies (Rolian et al., 2009; Nenko et al., 2018). Walking served not only as the primary method for locating food, water, and shelter but also played a crucial role in social interactions and the exploration of new territories. Running, particularly endurance running, was critical during hunting

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TABLE 3 Effects of participation in different sports on different personality traits.

	Model 1					Model 2				
	Neuroticism	Extraversion	Openness (negative scoring)	Agreeableness	Conscientiousness	Neuroticism	Extraversion	Openness (negative scoring)	Agreeableness	Conscientiousness
Jump rope	−0.314*** (0.034)	0.118** (0.042)	−0.251*** (0.023)	0.214** (0.078)	0.524*** (0.073)	−0.477*** (0.035)	0.301** (0.043)	−0.344*** (0.023)	0.681*** (0.081)	0.919*** (0.076)
Roller skating	0.073 (0.039)	0.152** (0.049)	0.041 (0.026)	0.224* (0.090)	0.219* (0.085)	0.128** (0.041)	0.095 (0.051)	0.075** (0.027)	0.097 (0.095)	0.106 (0.090)
Chase and capture game	0.215*** (0.030)	0.055 (0.038)	0.084*** (0.020)	−0.129 (0.069)	−0.298*** (0.066)	0.240*** (0.032)	0.035 (0.039)	0.096*** (0.021)	−0.182* (0.073)	−0.345*** (0.069)
Walking exercise	−0.482*** (0.049)	0.457*** (0.060)	−0.262*** (0.032)	1.489*** (0.111)	1.170*** (0.105)	−0.667*** (0.050)	0.683*** (0.062)	−0.367*** (0.033)	2.049*** (0.117)	1.650*** (0.110)
Cycling	−0.051 (0.034)	−0.106* (0.041)	−0.042 (0.022)	−0.251** (0.077)	−0.130 (0.072)	−0.074* (0.035)	−0.064 (0.043)	−0.058* (0.023)	−0.210** (0.081)	−0.074 (0.076)
Jogging or running	−0.477*** (0.046)	0.639*** (0.057)	−0.134*** (0.031)	1.936*** (0.105)	1.404*** (0.010)	0.662*** (0.048)	0.867*** (0.059)	−0.224*** (0.031)	2.454*** (0.111)	1.834*** (0.104)
Swimming	0.059 (0.044)	−0.033 (0.054)	0.087** (0.029)	−0.144 (0.100)	−0.144 (0.095)	0.075 (0.045)	0.015 (0.056)	0.080** (0.030)	−0.077 (0.106)	−0.047 (0.010)
Baseball, softball	0.137** (0.053)	−0.058 (0.065)	0.186*** (0.035)	−0.190 (0.120)	−0.269* (0.113)	0.207*** (0.054)	−0.144* (0.067)	0.236*** (0.036)	−0.443*** (0.127)	−0.483*** (0.119)
Dance-based movement	0.103** (0.039)	0.035 (0.048)	0.041 (0.026)	−0.122 (0.089)	0.106 (0.084)	0.056 (0.039)	0.021 (0.048)	0.004 (0.026)	0.102 (0.091)	0.231** (0.085)
Badminton	−0.049 (0.034)	0.230*** (0.042)	0.008 (0.022)	0.353*** (0.077)	0.252** (0.073)	−0.045 (0.035)	0.211*** (0.043)	0.024 (0.023)	0.279** (0.081)	0.172* (0.076)
Skateboarding	0.023 (0.043)	−0.005 (0.053)	0.105*** (0.029)	0.072 (0.099)	−0.069 (0.093)	0.019 (0.045)	−0.019 (0.056)	0.104*** (0.030)	0.065 (0.105)	−0.88 (0.098)
Soccer	−0.024 (0.037)	0.091* (0.046)	−0.083** (0.025)	−0.0104 (0.085)	0.092 (0.080)	0.019 (0.038)	0.101* (0.047)	−0.061* (0.025)	−0.234** (0.089)	0.027 (0.084)
Volleyball	−0.011 (0.039)	0.055 (0.048)	−0.025 (0.026)	0.113 (0.089)	0.112 (0.084)	−0.022 (0.040)	0.074 (0.050)	−0.036 (0.026)	0.210* (0.094)	0.191* (0.088)
Basketball	−0.057 (0.035)	0.285*** (0.043)	−0.062** (0.023)	0.313*** (0.080)	0.324*** (0.075)	−0.033 (0.035)	0.363*** (0.044)	−0.049* (0.023)	0.257** (0.082)	0.357*** (0.077)
Ice skating	0.136* (0.053)	−0.088 (0.066)	0.083* (0.025)	−0.415** (0.122)	−0.292* (0.115)	0.167** (0.055)	−0.139* (0.068)	0.106** (0.036)	−0.512*** (0.129)	−0.393** (0.121)

(Continued)

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TABLE 3 (Continued)

	Model 1					Model 2				
	Neuroticism	Extraversion	Openness (negative scoring)	Agreeableness	Conscientiousness	Neuroticism	Extraversion	Openness (negative scoring)	Agreeableness	Conscientiousness
Cross-country skiing	0.694***	−0.713***	0.504***	−1.551***	−1.428***	0.838***	−0.853***	0.567***	−1.870***	−1.685***
	(0.056)	(0.069)	(0.037)	(0.128)	(0.121)	(0.058)	(0.072)	(0.038)	(0.135)	(0.127)
Cross-country skiing	0.054	0.121**	−0.007	0.206**	0.192**	0.018	0.176***	−0.029	0.323***	0.295**
	(0.030)	(0.037)	(0.020)	(0.068)	(0.064)	(0.031)	(0.038)	(0.020)	(0.071)	(0.067)
Feature control	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No

The control variables include gender, place of residence, parents' education levels, parents' occupations, family economic conditions, the frequency of vigorous exercise during physical education classes in the past 7 days, and family economic relationships. "*" indicates $p < 0.05$, "**" indicates $p < 0.01$, "***" indicates $p < 0.001$. In the personality traits, openness is scored negatively, meaning that a lower openness score indicates better development of openness traits. In each column, the coefficient with the largest absolute value that is significant is marked with "underline" (only considering sports activities that contribute to positive personality development). The coefficients shown in parentheses are standard errors.

and when evading predators. Engaging in these activities today may trigger deep-seated psychological and physiological mechanisms that were developed to navigate these ancient challenges, contributing positively to the development of personality traits. This suggests that by participating in walking and running, modern individuals may tap into these evolutionary adaptations, which can enhance traits such as resilience, social connectivity, and exploratory behavior, ultimately supporting the positive evolution of personal characteristics.

4.2 Gender differences in the effects of sports participation on personality development

Our analysis reveals distinct gender-based preferences in sports that are optimal for the development of certain personality traits: men benefit more from jogging or running, particularly for enhancing neuroticism, agreeableness, and conscientiousness, while women gain more from walking exercises. In contrast, there are no gender differences in the optimal sports for boosting extraversion and openness, with both jogging or running, and walking exercises serving as effective activities. This pattern aligns with gender role theory, which posits that societal expectations around emotional expression and behaviors differ for men and women, influencing their personality development (Diekman and Schmader, 2024). Sports, as a form of behavior, are influenced by these gender roles. Typically, men are encouraged to participate in intense sports, while women are steered toward gentler activities. Meeting these societal expectations then triggers feedback from society, fostering personality development (Gantz and Wenner, 1991). By integrating our findings with gender role theory, we offer a fresh perspective on how gender roles through sports participation shape individual personality traits. This not only reaffirms the relevance of gender role theory in contemporary society but also broadens its scope, particularly in explaining gender-specific impacts of sports on personality traits. Moreover, our study underscores the importance of considering gender roles in the choice of sports and their potential influence on personality development, providing a solid empirical foundation for further research into gender role theory.

Our findings can also be interpreted through the lens of evolutionary psychology. Historically, men and women performed distinct roles within early human societies. Men primarily engaged in hunting and group protection (Panter-Brick, 2002), activities that involve chasing and quick movements, hence making jogging or running a natural fit for enhancing traits that were beneficial in these contexts. This evolutionary backdrop explains why these activities are particularly suited to men today. Conversely, women in ancient times were more engaged in gathering (Panter-Brick, 2002), an activity that involves walking and careful selection, aligning closely with the nature of walking exercises. This historical alignment explains why walking is an optimal activity for women. Even though modern lifestyles differ vastly from those of our ancestors, the adaptive traits ingrained in our genetic makeup continue to influence our sports preferences and how these activities mold our personalities. The distinct sports preferences between genders and their differential impact on personality traits can be viewed as modern manifestations of these ancient adaptive behaviors. This perspective not only enriches our understanding of

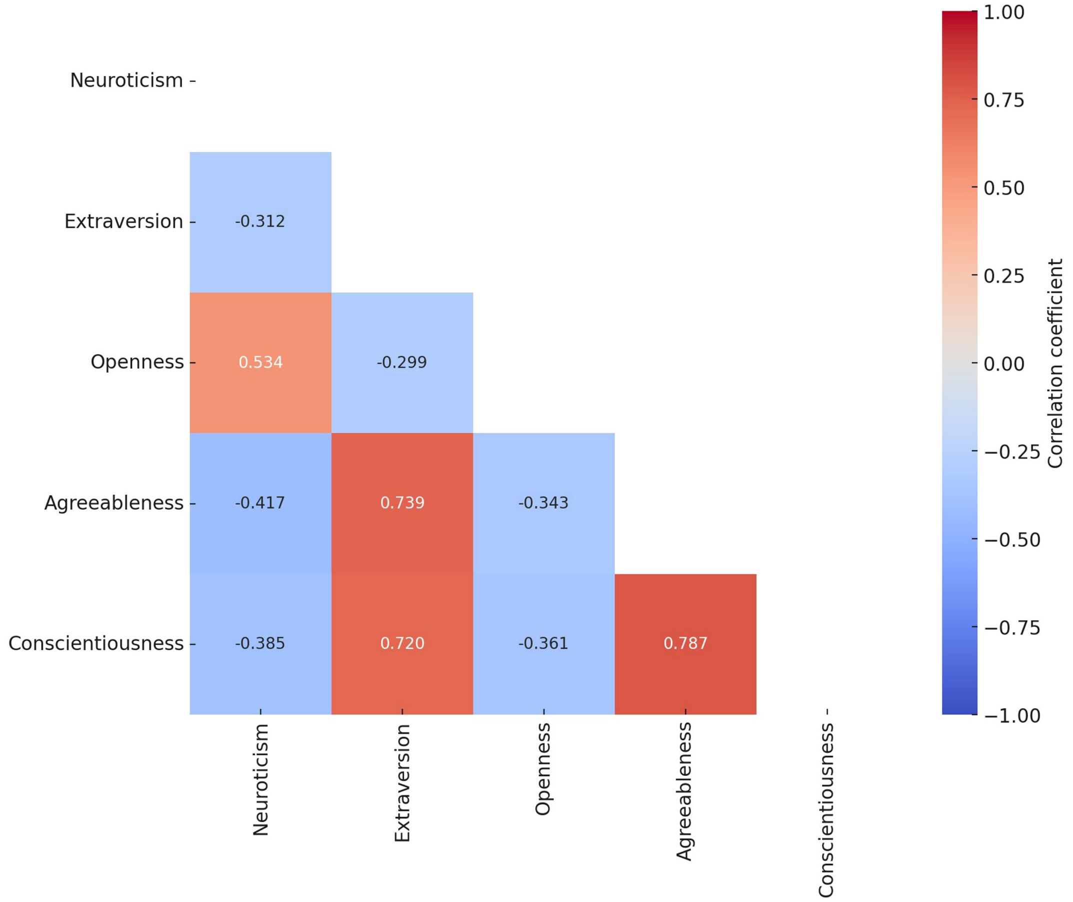

FIGURE 6
Pearson correlation coefficients between personality traits.

gender-specific sports preferences but also highlights how deep-rooted evolutionary patterns continue to shape behaviors in contemporary settings.

The observed results may also be associated with the differing emotional regulation strategies employed by men and women. Various studies indicate that the ways individuals cope with stress significantly influence their personality development (Shiner, 2009; Pérez-Chacón et al., 2023; Schlatter et al., 2022). Men, in particular, are more inclined to use high-intensity sports as a means to regulate their emotions (Piekarska and Martowska, 2020). This preference for vigorous physical activities as a coping mechanism is a significant factor contributing to the gender differences in selecting optimal sports activities. This insight not only highlights the role of sports in emotional management but also sheds light on how traditional gender roles may influence the selection of sports as a tool for psychological well-being.

4.3 Adverse effects of cross-country skiing on personality traits

The earlier empirical analysis revealed that cross-country skiing notably and negatively influences all personality traits. Moreover, among sports that detrimentally affect personality trait development, the negative impact coefficients associated with cross-country skiing are consistently the most pronounced. This pattern persists even when accounting for other control variables. Therefore, it suggests that cross-country skiing should be cautiously considered or possibly avoided for those seeking to enhance any aspect of their personality positively. This recommendation is based on its consistent association with adverse outcomes in personality development, making it less suitable for those aiming to foster positive psychological growth.

The relationship between cross-country skiing and personality traits can be understood through several lenses: First, Psychological Stress: Cross-country skiing depends heavily on variable environmental factors such as snow quality and weather conditions, which introduce significant risks. Participants' awareness of these risks can lead to increased fear and anxiety (Raue et al., 2019), accumulating stress that adversely impacts long-term psychological health and negatively influences personality traits (Frenkel et al., 2019). Second, Skill Requirements: Cross-country skiing demands extensive learning and high skill levels, involving challenges like endurance and technical prowess. The intense challenges and potential frustrations encountered can negatively affect personality traits by undermining individuals' confidence and satisfaction (Taylor et al., 2022). Third, Social Interaction: The sport often lacks social interaction, focusing instead on solitary engagements with nature. This isolation can restrict social skill development, inhibiting

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TABLE 4 **Effects of participation in different sports on different personality traits.**

	Neuroticism	Extraversion	Openness (negative scoring)	Agreeableness	Conscientiousness
Jump rope	−0.314***	0.118**	−0.251***	0.214**	0.524***
	(0.032)	(0.041)	(0.022)	(0.075)	(0.070)
Roller skating	0.073*	0.152**	0.041	0.224*	0.219**
	(0.037)	(0.048)	(0.025)	(0.089)	(0.083)
Chase and capture game	0.215***	0.055	0.084***	−0.129*	−0.298***
	(0.026)	(0.036)	(0.019)	(0.066)	(0.061)
Walking exercise	−0.482***	0.457***	−0.262***	1.489***	1.170***
	(0.055)	(0.063)	(0.035)	(0.119)	(0.112)
Cycling	−0.051	−0.106**	−0.042*	−0.251**	−0.130
	(0.030)	(0.041)	(0.021)	(0.072)	(0.067)
Jogging or running	−0.477***	0.639***	−0.134***	1.936***	1.404***
	(0.051)	(0.059)	(0.032)	(0.112)	(0.104)
Swimming	0.059	−0.033	0.087**	−0.144	−0.144
	(0.042)	(0.053)	(0.029)	(0.099)	(0.092)
Baseball, softball	0.137**	−0.058	0.186***	−0.190	−0.269*
	(0.053)	(0.064)	(0.036)	(0.121)	(0.114)
Dance-based movement	0.103**	0.035	0.041	−0.122	0.106
	(0.037)	(0.047)	(0.025)	(0.087)	(0.081)
Badminton	−0.049	0.230***	0.008	0.353***	0.252***
	(0.030)	(0.040)	(0.021)	(0.072)	(0.068)
Skateboarding	0.023	−0.005	0.105***	0.072	−0.069
	(0.040)	(0.053)	(0.028)	(0.096)	(0.090)
Soccer	−0.024	0.091*	−0.083**	−0.104	0.092
	(0.034)	(0.044)	(0.023)	(0.082)	(0.076)
Volleyball	−0.011	0.055	−0.025	0.113	0.112
	(0.035)	(0.046)	(0.024)	(0.084)	(0.078)
Basketball	−0.057	0.285***	−0.062**	0.313***	0.324***
	(0.032)	(0.042)	(0.022)	(0.077)	(0.072)
Ice skating	0.136*	−0.088	0.083*	−0.415**	−0.292*
	(0.055)	(0.064)	(0.038)	(0.125)	(0.116)
Cross-country skiing	0.694***	−0.713***	0.504***	−1.551***	−1.428***
	(0.062)	(0.071)	(0.042)	(0.137)	(0.130)

(Continued)

TABLE 4 (Continued)

	Neuroticism	Extraversion	Openness (negative scoring)	Agreeableness	Conscientiousness
Other	0.054*	0.121**	−0.007	0.206**	0.192**
	(0.026)	(0.036)	(0.018)	(0.064)	(0.060)
Feature control	Yes	Yes	Yes	Yes	Yes

Statistical significance is denoted as follows: "*" indicates $p<0.05$, "**" indicates $p<0.01$, and "***" indicates $p<0.001$. The analysis controls for several variables: gender, residential location, levels of parental education, parental employment status, family economic conditions, the frequency of intense physical activity in physical education classes over the previous week, and the dynamics of family economics. Within each column of the results, the most significant coefficients—those with the largest absolute values—are highlighted with "underline," focusing only on sports activities that foster beneficial development in personality traits.

growth in traits like agreeableness (Leep Hunderfund et al., 2022). Fourth, Physical and Emotional Exhaustion: The physical demands of cross-country skiing require significant endurance and strength, leading to exhaustion. This continuous strain can heighten susceptibility to mood disorders such as anxiety and depression, fostering a more neurotic disposition (Broddadóttir et al., 2021; Sosnowska et al., 2019). Fifth, Cultural Factors: While the sport can confer community recognition and status (Ballman et al., 1981), primarily participating to fulfill external expectations rather than for personal fulfillment can increase stress and negatively impact personality development (Weinstein and Ryan, 2011). This multifaceted perspective highlights how cross-country skiing's demanding nature can shape personality traits, often posing challenges that may hinder positive development.

5 Practical value

By thoroughly examining the role of gender differences in the relationship between sports participation and personality development, we can gain a deeper understanding of the broad impact of sports on individual growth, thereby supporting efforts to create a healthier and more balanced society.

At the policy level, our findings can provide valuable insights for policymakers in the fields of education and public health. By elucidating the relationships between gender, exercise frequency, sports disciplines, and personality traits, this research can assist policymakers in formulating more inclusive and targeted sports promotion strategies. For instance, educational authorities might tailor physical education curricula and exercise schedules to address the distinct developmental needs of male and female students, thereby enhancing their personality development.

On a practical level, our results offer important guidance for sports coaches, psychological counselors, and sports enthusiasts. Recognizing how gender, exercise frequency, and participation in different sports disciplines influence personality development can help practitioners design more personalized training and development plans that account for gender-specific factors. This approach could more effectively foster the physical and mental well-being, as well as the positive personality development, of both athletes and the general population. Furthermore, this research provides fresh avenues for interdisciplinary studies in the fields of sports science and psychology, encouraging collaborative exploration of these topics.

6 Limitations and future research directions

6.1 Limitations

This study's sample, consisting of middle and high school students from 17 cities within Shandong Province, while sizable, is regionally confined, potentially limiting the findings' applicability and generalizability. Cultural and economic differences across regions, along with varying levels of engagement in physical activities, could differentially impact adolescent personality traits.

In terms of analytical methods, this study employs the seemingly unrelated regression model. Although this model accounts for the

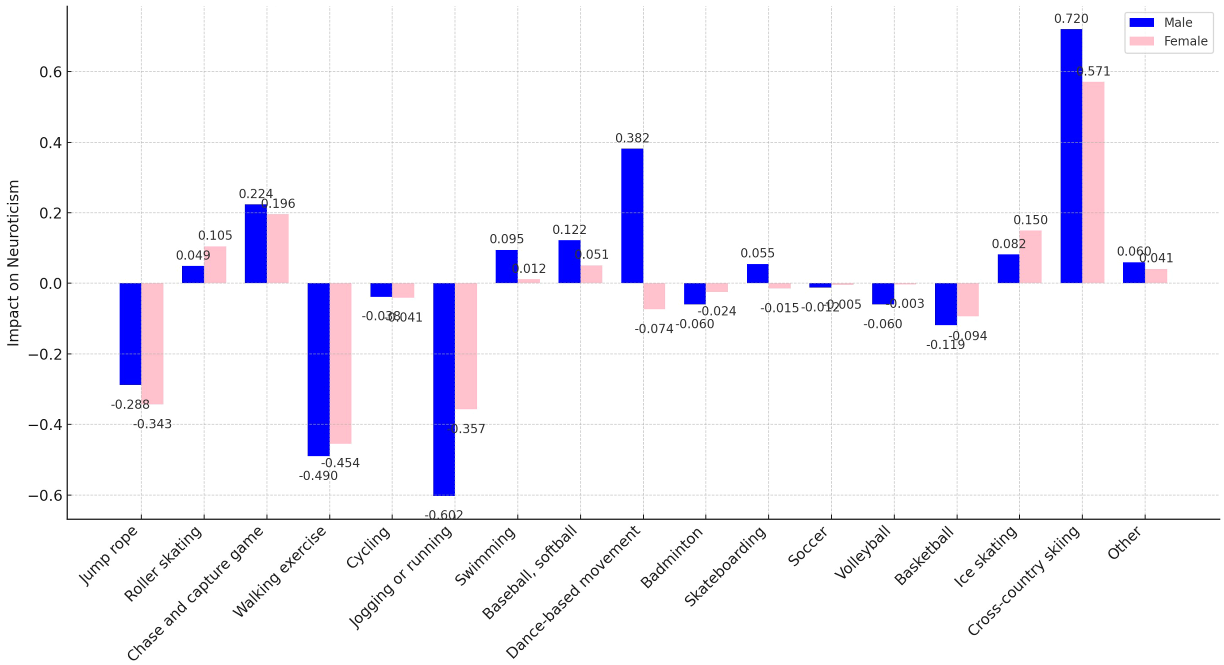

FIGURE 7
Impact of participation in different sports on neuroticism by gender.

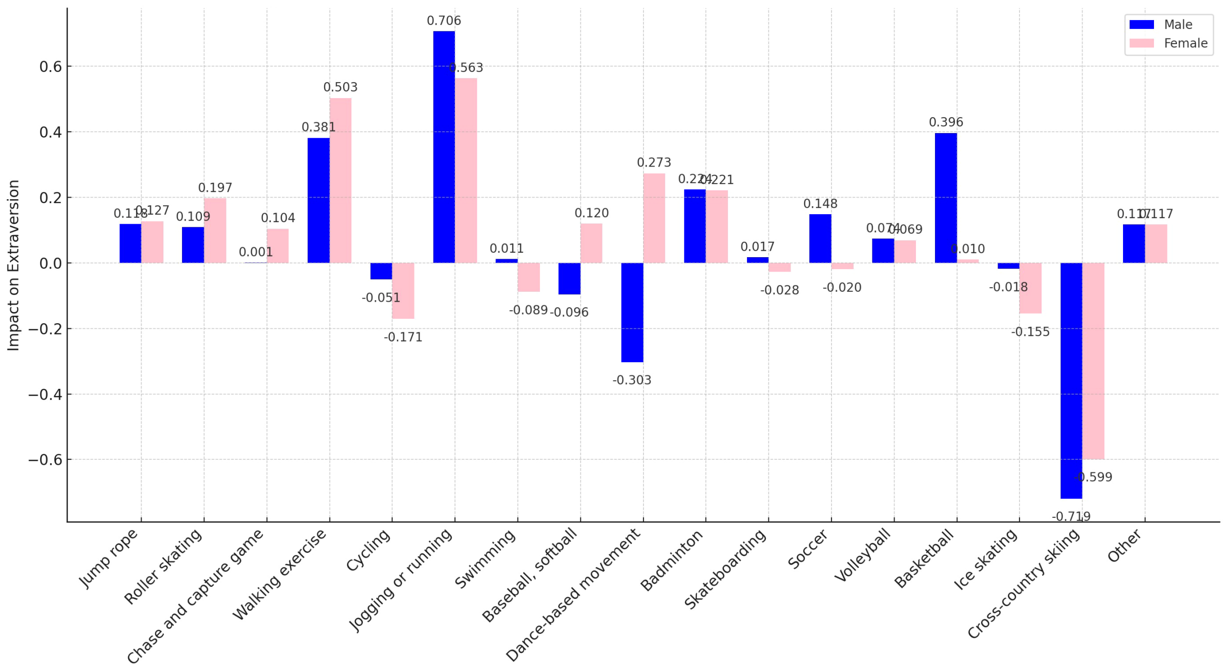

FIGURE 8
Impact of participation in different sports on openness by gender.

correlations between dependent variables and improves model efficiency, it is still based on the assumption that all observations are independent of each other. This assumption may not hold, especially when the sample exhibits clustering based on unobserved characteristics. Additionally, the data used in this study are cross-sectional, making it impossible to establish causal relationships between variables, which limits our understanding of how participation in sports influences personality traits over time. Finally, due to limitations of the database itself, some confounding variables that might affect both sports participation and personality traits could not be controlled for in the analysis, which limits the certainty of the study's findings.

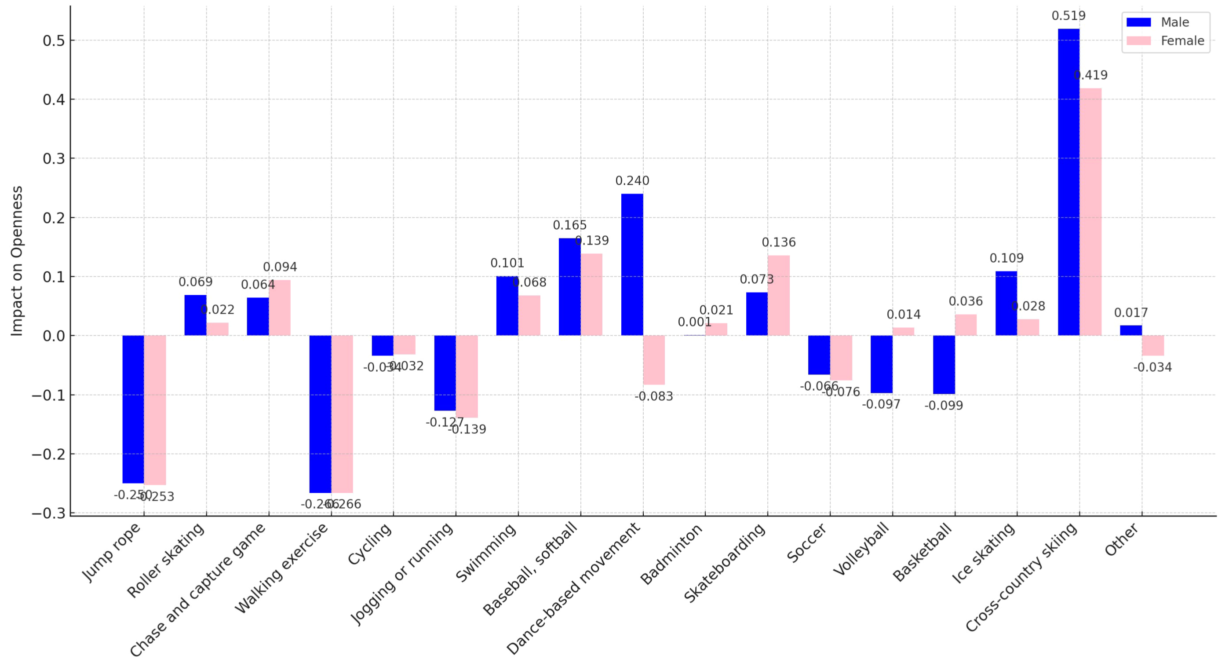

FIGURE 9
Impact of participation in different sports on extraversion by gender.

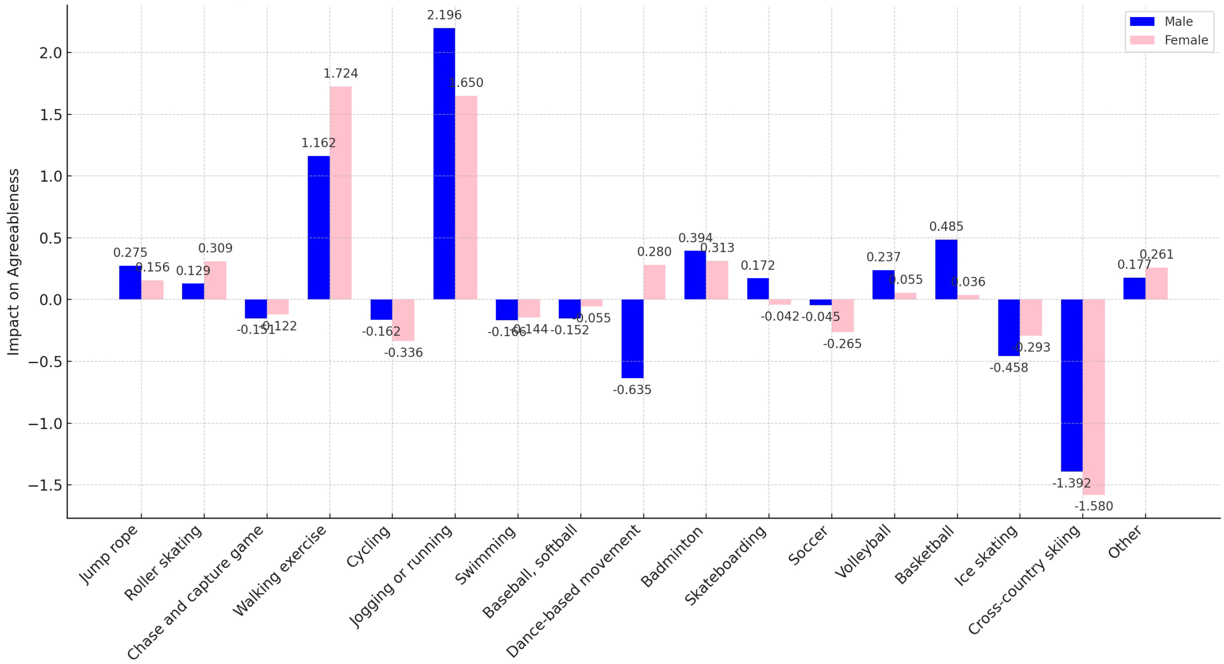

FIGURE 10
Impact of participation in different sports on agreeableness by gender.

6.2 Future research directions

Building on the insights from this study, future research can take several paths to deepen our understanding of how sports influence adolescent personality development and explore ways to harness sports for positive personality growth.

Firstly, although we found that walking and jogging/running were prominent in promoting the development of personality traits, the psychological mechanisms behind this effect were not analyzed. We hope that future research will focus on empirical analysis of these psychological mechanisms to better understand the complex relationship between physical activity and personality traits. Secondly,

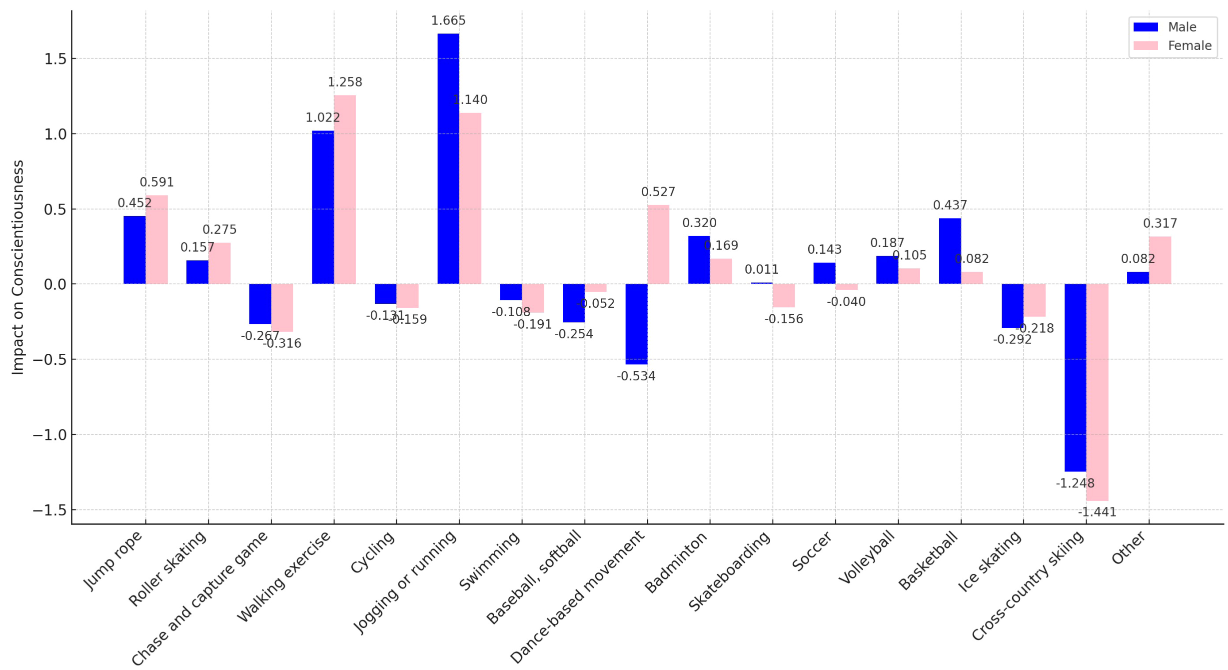

FIGURE 11
Impact of participation in different sports on conscientiousness by gender.

more granular studies on different sports types are needed. While this research has considered various sports, detailed analyses on how specific sports and their intensity, social aspects, and skill demands influence personality traits are still required. Such studies can help identify which sports are most beneficial for certain personality traits. Lastly, further investigation into gender differences is essential. Our findings highlight gender as a key factor affecting how sports influence personality traits. Future studies should explore the underlying mechanisms of these gender differences more comprehensively, incorporating physiological, psychological, and sociocultural dimensions. Research could include examining how different genders experience sports psychologically and how these experiences shape personality development. These avenues promise to enrich our understanding of sports as a developmental tool and tailor approaches that leverage physical activity to foster desirable personality traits in youths.

Data availability statement

The raw data used in this study, as well as the Stata code for processing the data, are available upon request from the corresponding author. Access to raw data may be subject to restrictions based on e.g., ethical considerations, confidentiality agreements.

Ethics statement

Ethical review and approval, and written informed consent, were not required for this study in accordance with the local legislation and institutional requirements. The Database of Youth Health' used in this study is publicly available data. Therefore, no ethical approval or informed consent was required as the data were fully anonymized and complied with all relevant ethical and legal guidelines.

Author contributions

YG: Writing – review & editing, Writing – original draft, Conceptualization, Data Curation, Visualization, Validation, Formal analysis. LC: Writing – review & editing, Writing – original draft, Data Curation, Visualization, Validation, Formal analysis. XL: Writing – review & editing, Writing – original draft, Conceptualization, Data Curation, Supervision, Resources, Formal analysis.

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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 an exercise intervention on maternal depression, anxiety, and fatigue: a systematic review and meta-analysis

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Background: Existing meta-analyses suggest that exercise intervention may play a crucial therapeutic role in improving maternal depression, anxiety and fatigue symptoms. However, the efficacy varies across different exercise content, duration, frequency, cycle, intensity, format and intervention period.

Objective: Using meta-analysis to propose the best intervention program and examine the effect of exercise intervention on maternal depression, anxiety, and fatigue.

Methods: Five databases (PubMed, Web of Science, Embase, Cochrane Library, CNKI) were searched from inception to June 2024, a total of 37 literatures were included. The methodological quality of the included literatures was assessed using the Cochrane Risk of Bias tool and the PEDro scale. When heterogeneity was high, we used random-effects models. Funnel plots were used to assess publication bias. Sensitivity analysis was used to verify the robustness of the combined results. Subgroup analysis was used to explore sources of heterogeneity.

Results: Exercise has beneficial effects on the improvement of maternal depression [$g = -0.71$, 95%CI (−0.93, −0.49), $p = 0.00$], anxiety [$g = -1.09$, 95%CI (−1.42, −0.76), $p = 0.00$] and fatigue [$g = -0.64$, 95%CI (−0.88, −0.40), $p = 0.00$] symptoms. Postnatal interventions may be more effective than prenatal. Low-moderate intensity yoga with group + individual, 4–5 times/week, 40–60 min/time, duration 4–8 weeks is most effective in improving depressive symptoms. Low-intensity yoga with group + individual, 4–5 times/week, 40–60 min/time, duration 4–8 weeks is most effective for improving anxiety symptoms. Low-intensity Pilates with group, 1–2 times/week, 40–60 min/time, duration 4–8 weeks is most effective for improving fatigue symptoms.

Conclusion: This meta-analysis demonstrates the positive effect of exercise on improving maternal depression, anxiety and fatigue and suggests the best intervention program. Maternal perceptions that postpartum exercise is safer may account for the better outcomes of postpartum intervention. Further higher quality and large-scale trials are needed to substantiate our findings.

Systematic review registration: https://www.crd.york.ac.uk/PROSPERO/, CRD42024567987.

KEYWORDS

exercise intervention, maternal, depression, anxiety, fatigue, meta-analysis

1 Introduction

Maternal, including pregnant and postpartum women, experience significant physical, emotional, and financial changes during pregnancy and childbirth. During this period, women are more susceptible to depression and anxiety compared to other life stages (Hunter et al., 2024). It may also one of the most fatiguing phases of a woman's life (Wilson et al., 2019). Globally, the prevalence of prenatal and postpartum depression ranges from 10 to 33.3% (Ji et al., 2024); prenatal and postpartum anxiety ranges from 16 to 25% (Glasheen et al., 2010; Field, 2017) and maternal fatigue is as high as 41–90% (Nazik and Eryilmaz, 2014; Reeves et al., 1991). The high prevalence of maternal depression, anxiety, and fatigue significantly affects maternal physical and mental health and quality of life, even causing harm to the fetus or baby (Dunkel Schetter and Tanner, 2012), e.g., low birth weight (de Bruijn et al., 2009), developmental delay and preterm labor (Field, 2010). Compared to non-depressed, anxious maternal, depressed, anxious maternal are more likely to be fatigued (Taylor and Johnson, 2013), have a greater fear of childbirth (Hall et al., 2009), and their newborns are at higher risk for depression and anxiety during childhood and adolescence (Kingston et al., 2012). Although medication is an important treatment for depression and anxiety, it is important to consider the adverse effects of antidepressant and anxiolytic medications, e.g., may cause congenital disability in newborns and maternal headache and drowsiness (Latendresse et al., 2017). Evidence suggests that fatigue can lead to decreased maternal physical and mental work capacity and even feel helpless, seriously affecting maternal and baby health and life satisfaction (Liu et al., 2020), and may exacerbate depression and anxiety symptoms (Dennis and Ross, 2005).

Exercise, as a safe and practical non-pharmacological intervention, is important for treating maternal depression, anxiety and fatigue (Cleare et al., 2015). The results of a meta-analysis showed that after exercise intervention, significant and overall improvements in maternal depression and anxiety symptoms were observed (Liu et al., 2022). This may be due to the fact that appropriate exercise can regulate the maternal endocrine system, activate potential targets in the brain, plus the concentration of monoamine neurotransmitters in the brain, to achieve the objective of improving the depression and anxiety symptoms (Gujral et al., 2017; Nascimento et al., 2015). Increasing prenatal weight, postpartum debilitating mobility and physical inactivity are important causes of maternal fatigue (Badr and Zauszniewski, 2017; Liu et al., 2024). Research has confirmed that exercise interventions can improve maternal self-care, daily activity and sleep quality, and alleviate low back pain, all of which can help improve physical fatigue (Jia et al., 2021). Furthermore, exercise can alleviate bad moods, reduce maternal body image worries, which helps to improve psychological fatigue (Nascimento et al., 2014). Currently, exercise intervention is widely encouraged by virtue of its advantages of convenience, economy and side effects. However, the effects of different exercise content, duration, frequency, cycle, format, intensity and intervention period remain unclear. As more women exercise around pregnancy to improve physical and mental health and relieve fatigue, researchers and clinicians need to identify and implement best practices in treatment. Based on this, the primary aim of this study is to investigate the effects of different exercise content, duration, frequency, cycle, format, intensity, and intervention period on the overall intervention effect, and to propose the best intervention program. Analysis the effects of exercise interventions on maternal depression, anxiety, and fatigue. To provide evidence and references for the development of more targeted and comprehensive exercise intervention programs.

2 Methods

The study followed the PRISMA guidelines and the Cochrane Handbook for meta-analysis and systematic review (Page et al., 2021; Higgins et al., 2019). The research was registered on the International Prospective Register of Systematic Reviews (PROSPERO), identifier: CRD42024567987. Conducted a self-review based on the PRISMA 2020 Checklist (Supplementary material).

2.1 Inclusion and exclusion criteria

According to the PICOS principles, literature inclusion criteria included: (1) Participants: maternal, age ≥ 18, without pregnancy complications or other illnesses. (2) Interventions: the intervention group performed exercise (yoga, aerobic exercise, etc.). (3) Controls: the control group received non-exercise (usual care, daily activities, etc.). (4) Outcomes: depression, anxiety and fatigue rating scales, results presented as mean (M) ± standard deviation (SD). (5) Types of studies: randomized controlled trials (RCT).

Exclusion criteria: Studies involving (1) maternal participants with gestational diabetes, high blood pressure, other diseases, or severe mental disorders requiring pharmacological intervention. (2) non-RCT, conference abstracts, and review articles. (3) Studies with incomplete data reporting. (4) Non-Chinese and non-English literature. (5) Animal studies.

2.2 Literature search

Search in PubMed, Web of Science, Embase, Cochrane Library, and CNKI databases from inception to June 2024.The search strategy was based on medical subject headings (MeSH) and free words with "AND" and "OR" linking, e.g.: ("Pregnancy [Mesh]" OR "Postpartum Period [Mesh]" OR "maternal" OR "pregnant" OR "post-pregnancy" OR "Postpartum Period") AND ("Exercise [Mesh]" OR "Exercise interventions" OR "physical exercise" OR "sport" OR "physical activity" OR "exercise" OR "yoga") AND ("Depression [Mesh]" OR "Depression, Postpartum" OR "Anxiety [Mesh]" OR "Fatigue [Mesh]" OR "Burnout" OR "tired"). A subsequent supplement was conducted to trace relevant systematic reviews and references of included papers for those not having been retrieved. The complete search strategy is in Supplementary material.

2.3 Literature screening

The retrieved literature was imported into Endnote X9.1, after removing duplicates, two researchers independently screened the titles and abstracts according to the inclusion and exclusion criteria, and then read the full texts for further screening. If the results were

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consistent, the literature was included in this study, if not, it will be discussed with the 3rd researcher until a consensus was reached.

2.4 Data extraction and coding strategy

Two researchers independently extracted data from the eligible literature using an agreed form, 98.35% concordance of data extracted by two researchers. Disagreements were discussed with the 3rd researcher until consensus was reached. The main components extracted were: (1) basic information about the included literature (first author, publication year, country); (2) subject characteristics (sample size, pregnancy week, other characteristics); (3) intervention in the experimental group (exercise content, single exercise time, frequency, exercise cycle, exercise form, intensity, intervention period); (4) intervention in the control group; and (5) measure tools.

Exercise content was coded as: yoga, Combination of aerobic exercise (including aerobic-based walking, dance, etc.) and Pilates. Single exercise time was coded as: 10–30 min/time, 40–60 min/time and 75–90 min/time. Exercise frequency was coded as: 1–2 times/week, 3 times/week and 4–5 times/week. Exercise cycle was coded as: 4–8 weeks, 9–12 weeks and 14–16 weeks. Exercise intensity was coded as: low, medium, low-medium and medium-high. Exercise format was coded as: group, individual and group + individual. Intervention period was coded as: prenatal, postpartum and prenatal+ postpartum.

2.5 Quality assessment

The methodological quality of the literature was evaluated using the Cochrane Risk Assessment Tool, which includes seven items: Random sequence generation, allocation concealment, blinding of participants and personnel, Blinding of outcome assessment, incomplete outcome data, selective reporting, other bias. Each literature was assessed in three options: high risk, unclear risk, and low risk. Quality risk assessment of the included literature was performed using the PEDro scale (<4: low quality, 4–5: medium quality, 6–8: high quality, and 9–10: very high quality). It was independently by two researchers, and when results were inconsistent, it was resolved by discussion with the 3rd researcher until a consensus was reached. In addition, we assessed the evidence level of the included literature according to the GRADE system (Supplementary material).

2.6 Statistical analysis

Review Manager 5.4 was used for the methodological quality assessment of the literature, and Stata17 was used for publication bias test (including Egger's test and Begg's test), sensitivity analyses, combining effect sizes, forest plotting, and subgroup analyses. The data used in this study are the change values of M and SD from baseline to endpoint. If it cannot be extracted directly, it is estimated according to the following formula: $M = M_2 - M_1$ (M_2 is the endpoint mean, M_1 is the baseline mean); $SD = \sqrt{SD_1^2 + SD_2^2 - (2 \times Corr \times SD_1 \times SD_2)}$ (SD_1 is the baseline SD, SD_2 is the endpoint SD), Corr is the correlation coefficient between the baseline and endpoint scores, conservatively set at 0.5 (Follmann et al., 1992; Fukuta et al., 2016). Effect sizes are expressed using Hedges' g (g) and 95% Cl. $g < 0.2$ indicates a small effect, $0.2 < g < 0.8$ indicates a medium effect, and $g > 0.8$ indicates a significant effect (Jacob, 1998). $I^2 < 50\%$ uses the fixed-effects model; $I^2 > 50\%$ uses the random-effects model to combine effect sizes, then conduct sensitivity and subgroup analyses (Higgins and Thompson, 2002). $p < 0.05$ was defined as statistically significant (Higgins et al., 2011).

3 Results

3.1 Study selection and characteristics

A total of 1,429 literatures were retrieved, 1,136 literature remained after eliminating duplicates, and 62 literatures were obtained by further screening based on title and abstract. Finally, 24 papers were excluded due to missing data, unavailability of full text, non-exercise intervention, non-RCT, and disease. A total of 37 papers were finally included, including 22 English papers and 15 Chinese papers (Figure 1).

3.2 Results of the quality assessment of the included literature

The 37 included literature all used randomized methods to allocate members of the experimental and control groups, provided complete data, reported results unselectively, and found no other bias. 13 literature described procedures for allocating concealment, and all literature were not blinded to the subjects and implementers (Figure 2). The quality of the included literatures was assessed using the PEDro scale. The average quality of the included literatures was 7.35, all included literatures demonstrated high methodological quality and there were no low-quality literatures (Supplementary material).

3.3 Characteristics of the included studies

There were 37 RCT. Thirty literatures included depression as an outcome indicator, and a total of 7 different measure tools were used, including the Edinburgh Postnatal Depression Scale (EPDS). Seventeen literatures included anxiety as an outcome indicator, and a total of 8 different measure tools were used, including the Hamilton Anxiety Rating Scale (HARS). Nine literatures included fatigue as an outcome indicator, and a total of seven different measure tools were used, including the Fatigue Assessment Instrument (FAI). The exercise content included yoga, aerobic exercise, etc.; the single exercise time ranged from 15 to 90 min; the frequency ranged from 1–5 times/week; the exercise cycle ranged from 4 to 16 weeks; the exercise intensities were mainly low-intensity, moderate-intensity, and low-moderate-intensity; the exercise formats included group format, individual format, and group + individual format; and the intervention Period includes prenatal intervention, postpartum intervention, and prenatal + postpartum intervention. In the control group, routine care and daily activities were used. The basic characteristics of the included literature are shown in Table 1.

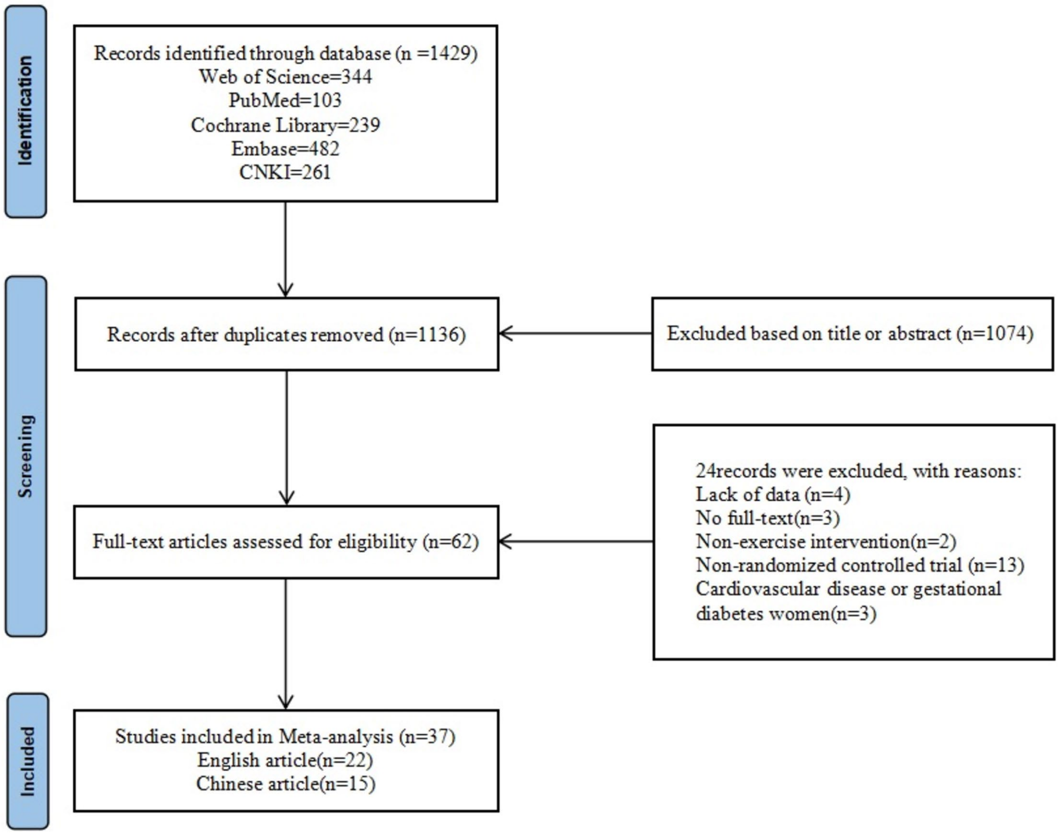

FIGURE 1
Literature screening flowchart.

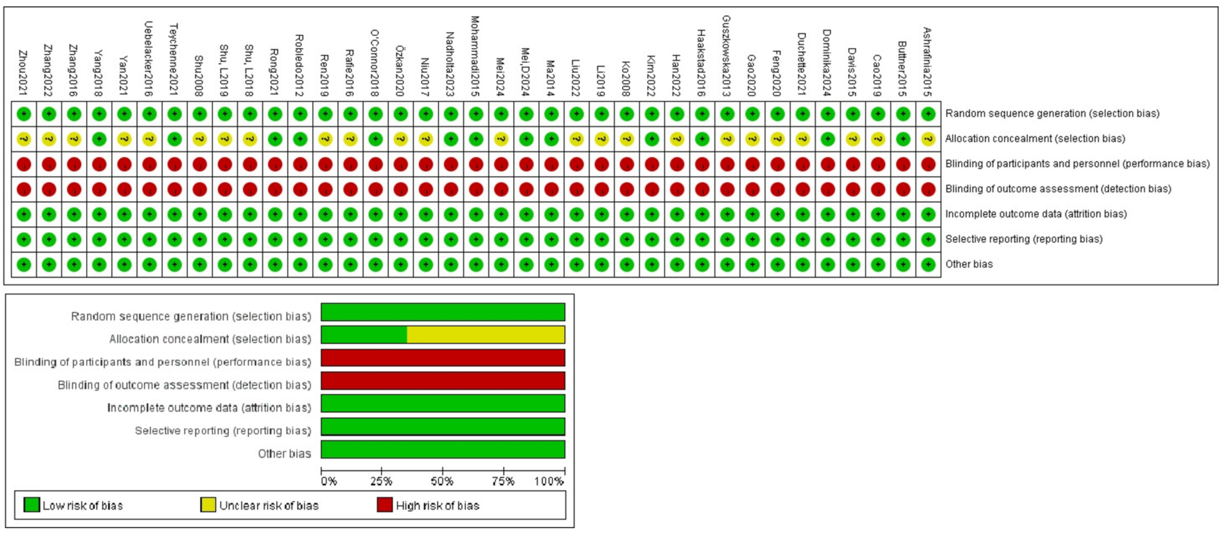

FIGURE 2
Literature quality evaluation.

3.4 Test for publication bias

Using Egger's test, Begg's test, and funnel plot to test for the presence of publication bias. There was no significant asymmetry in the 3 funnel plots (Figure 3). For the depression indicator, Egger's test ($Z = -1.51$, $p = 0.13$) and Begg's test ($Z = -1.78$, $p = 0.08$); for the anxiety indicator, Egger's test ($Z = -0.91$, $p = 0.36$) and Begg's test ($Z = -0.87$, $p = 0.43$); for the fatigue indicator, Egger's test ($Z = -1.39$, $p = 0.16$), Begg's test ($Z = -1.98$, $p = 0.08$). It showed that there was no significant publication bias among the studies for the 3 indicators.

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TABLE 1 Characteristics of the included literature.

First author	Country	Sample size (experimental group/control group)	Target sample	Intervention period	Intervention in the experimental group (exercise format)	Intervention in the control group	Exercise intensity	Frequency	Time	Exercise cycle	Measure tools
Ashrafinia (2015)	Iranian	80 (40/40)	Healthy postnatal women	Postnatal interventions (72 h after childbirth)	Pilates (individual exercises at home)	Non-participation	Low-Medium	5 times/week	30 min/time	8 weeks	MFI-20
Buttner (2015)	USA	57 (28/29)	Women with postnatal depression (within 12 months of delivery)	Postnatal interventions	Yoga (group exercise)	Non-participation	Low	2 times/week	60 min/time	8 weeks	HDRS, IDAS
Ca (2019)	China	128 (65/63)	Healthy pregnant women	Intervention at 1 weeks postpartum	Pelvic floor muscle rehabilitation exercises (individual exercises)	Routine care	Medium	3 times/day	20 min/time	14 weeks	EPDS, SAS
Davis (2015)	USA	46 (23/23)	Pregnant women with depression or anxiety (≤28 weeks of pregnancy)	Prenatal intervention	Yoga (group exercise)	Conventional treatment	Low	1 time/week	75 min/time	8 weeks	EPDS, STAI
Dominika (2024)	Polish	54 (34/20)	Healthy pregnant women (18–26 weeks of pregnancy)	Prenatal intervention	HIIT (group exercises)	Healthy lifestyle education	82–92% predicted heart rate	3 times/week	60 min/time	8 weeks	BDI-II
Duchette (2021)	USA	19(10/9)	Healthy pregnant women (12–26 weeks of pregnancy)	Prenatal intervention	Yoga (individual exercise at home)	Routine care	Low	1 time/week	90 min/time	10 weeks	POMS
Feng (2020)	China	100 (50/50)	Healthy pregnant women (28–36 weeks of pregnancy)	Prenatal intervention	Positive thinking yoga (Group exercise + Individual exercises at home)	Routine care	Low	Group practice: 1 time/week; Individual practice at home: 2 times/day	Group exercise: 60 min/time; Individual exercise at home: 20 min/time	4 weeks	SAS
Gao (2020)	China	84 (42/42)	Women with postnatal depression	Postnatal interventions	Yoga exercise (group exercise)	Routine care	Low-medium	4 times/week	60 min/time	6 weeks	HDRS, HARS
Guszkowska (2013)	Polish	97 (56/41)	Healthy pregnant women (20–34 weeks of pregnancy)	Prenatal intervention	Aerobic exercise (group exercise)	Routine care	Low-medium	2 times/week	50 min/time	8 weeks	POMS

(Continued)

TABLE 1 (Continued)

First author	Country	Sample size (experimental group/control group)	Target sample	Intervention period	Intervention in the experimental group (exercise format)	Intervention in the control group	Exercise intensity	Frequency	Time	Exercise cycle	Measure tools
Haakstad (2016)	Norway	105 (52/53)	Healthy pregnant women (12–24 weeks of pregnancy)	Prenatal intervention	Aerobic dance (group exercises)	Daily activities	Low-medium	2 times/week	60 min/time	12 weeks	WHOQOL, SF-36
Han (2022)	China	70 (35/35)	Women with postnatal depression	Postnatal interventions	Aerobic exercise (group exercise)	Cognitive therapy	60–80% predicted heart rate	3 times/week	40 min/time	12 weeks	EPDS
Kim (2022)	Korea	16 (8/8)	Healthy pregnant women under 40 years of age (24–28 weeks of pregnancy)	Prenatal intervention	Pilates (individual exercises at home)	Non-participation	50–60% predicted heart rate	2 times/week	50 min/time	8 weeks	EPDS
Ko (2008)	China-Taiwan	61 (31/30)	Healthy Postnatal Women	Prenatal intervention	Pilates (group practice)	Routine care	50–60% predicted heart rate	3 times/week	60 min/time	8 weeks	FSC, CES-D
Li (2019)	China	100 (50/50)	Women with postnatal depression	Postnatal interventions	Yoga exercise (group exercise)	Routine care + Psychological counseling	Low-medium	2 times/week	60 min/time	8 weeks	EPDS, SAS
Liu (2022)	China	86 (43/43)	Healthy Second-Trimester Pregnant Women	Postnatal interventions	Positive thinking yoga (Individual exercises at home)	Psychological counseling	Low-medium	2 times/week	30 min/time	8 weeks	EPDS, HAD
Ma (2014)	China	82 (40/42)	Women with postnatal depression	Postnatal interventions	Yoga exercise (group exercise)	Routine care	Low	4 times/week	60 min/time	8 weeks	EPDS, SAS
Mei (2024)	China	60 (30/30)	Healthy pregnant women (week of pregnancy ≤28 weeks)	Prenatal intervention	Aerobic exercise (yoga, tai chi) + resistance exercise (group exercises)	Routine antenatal education	Low	3 times/week	30 min/time	6 weeks	HARS
Mei, D (2024)	China	125 (63/62)	Women with postnatal depression	Postnatal interventions	Aerobic exercise (individual exercises)	Non-participation	Medium	1 time/3 days	30-40 min/time	12 weeks	EPDS
Mohammadi (2015)	Iranian	85 (43/42)	Healthy pregnant women (26–32 weeks of pregnancy)	Prenatal intervention + Postnatal interventions	Stretching and breathing exercises (individual exercises at home)	Routine prenatal and postnatal education	Medium	3 times/week	20-30 min/time	Until 8 weeks postpartum	EPDS, FIF

(Continued)

TABLE 1 (Continued)

First author	Country	Sample size (experimental group/control group)	Target sample	Intervention period	Intervention in the experimental group (exercise format)	Intervention in the control group	Exercise intensity	Frequency	Time	Exercise cycle	Measure tools
Nadholta (2023)	India	77 (34/43)	Healthy pregnant women	Prenatal intervention	Yoga (individual online exercises)	Routine care	Low	5 times/week	40-60 min/time	16 weeks	DASS-42
Niu (2017)	China	80 (40/40)	Women with postnatal depression	Intervention at 1 weeks postpartum	Yoga (Individual exercises at home)	Routine care	Low-medium	1 time/week	60 min/time	12 weeks	HDRS, HARS
O'Connor (2018)	USA	89 (44/45)	Healthy pregnant women (21–25 weeks of pregnancy)	Prenatal intervention	Resistance exercises + Aerobic exercise (group exercises)	Routine care	Low-medium	2 times/week	17 min/time	12 weeks	POMS
Özkan (2020)	Istanbul	65 (34/31)	Women with post-natal depression (age 25–35)	Postnatal interventions	Physical exercise (individual exercises)	Non-participation	Medium	5 times/week	30 min/time	4 weeks	EPDS
Rafie (2016)	Egypt	100 (50/50)	Healthy pregnant women (16–27 weeks of pregnancy)	Prenatal intervention	Aerobic exercise (group exercise)	Routine care	Medium	3 times/week	60 min/time	12 weeks	CES-D
Ren (2019)	China	38 (19/19)	Women with postnatal depression	Intervention at 6 weeks postpartum	Aerobic exercise (group exercise)	Daily activities	Medium	3 times/week	40 min/time	12 weeks	EPDS
Robledo (2012)	Colombia	74 (37/37)	Healthy pregnant women (16–20 weeks of pregnancy)	Prenatal intervention	Walking + aerobic exercise + stretching + relaxation (group exercise)	Daily activities	Medium	3 times/week	60 min/time	12 weeks	CES-D
Rong (2021)	China	64 (32/32)	Healthy pregnant women (18–27 weeks of pregnancy)	Prenatal intervention	Yoga exercise (group exercise)	Routine care	Low	3 times/week	60 min/time	12 weeks	EPDS, S-AI
Shu (2008)	China-Taiwan	68 (35/33)	Women with post-natal depression (age 20–35)	Intervention at 4 weeks postpartum	Stretching + relaxation exercises (group exercises + individual exercises at home)	Non-participation	Medium	Group exercises: 1 time/week; Individual exercises at home: 2 times/week	60 min/time	12 weeks	EPDS

(Continued)

TABLE 1 (Continued)

First author	Country	Sample size (experimental group/control group)	Target sample	Intervention period	Intervention in the experimental group (exercise format)	Intervention in the control group	Exercise intensity	Frequency	Time	Exercise cycle	Measure tools
Shu, L (2018)	China	115 (55/60)	Pregnant women with anxiety disorders (10–32 weeks of pregnancy)	Prenatal intervention	Positive Thinking Yoga (Group exercise + Individual exercise at home)	Psychological counseling	Low	Group practice: 1 time/week; Individual practice at home: 2 times/day	Group exercise: 60 min/time; Individual exercise at home: 20 min/time	4 weeks	SAS
Shu, L (2019)	China	86 (43/43)	Pregnant women with anxiety or depression (10–28 weeks of gestation)	Prenatal intervention	Group Positive Thinking Yoga (group exercise)	Psychological counseling	Low	1 time/week	60 min/time	6 weeks	EPDS, SAS
Teychenne (2021)	Australia	62 (32/30)	Women with postnatal depression (3–9 months postnatal)	Postnatal interventions	Family physical activity (Individual exercise at home)	Daily activities	Medium	Self-organization	Self-organization	12 weeks	EPDS
Uebelacker (2016)	USA	20 (12/8)	Pregnant women with depression (12–26 weeks of gestation)	Prenatal intervention	Yoga (group exercise + individual practice at home)	Mom-Baby Wellness Workshop (MBWW)	Low	2 times/week	75 min/time	9 weeks	EPDS
Yan (2021)	China	246 (123/123)	Healthy pregnant women (28 weeks of pregnancy and above, age 35–40)	Prenatal intervention	Fertility dance exercise (group exercise + individual exercise)	Routine care	Low-Medium	1 time/week	90 min/time	Until 6 weeks postpartum	EPDS
Yang (2018)	China-Taiwan	129 (64/65)	Healthy Postnatal Women	Intervention at 6 weeks postpartum	Aerobic gymnastics (individual exercises)	Routine care	Low	3 times/week	15 min/time	12 weeks	PFS, EPDS
Zhang (2016)	China	164 (82/82)	Healthy pregnant women	prenatal intervention	Yoga exercise (group exercise)	Routine care	Low	2 times/week	75 min/time	8 weeks	SDS, SAS
Zhang (2022)	China	209 (109/100)	Healthy pregnant women (24–27 weeks of pregnancy)	Prenatal intervention	Childbirth ball exercises based on abdominal core training (individual exercises)	Routine care	Medium	4 times/week	30 min/time	8 weeks	FAI

(Continued)

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TABLE 1 (Continued)

First author	Country	Sample size (experimental group/control group)	Target sample	Intervention period	Intervention in the experimental group (exercise format)	Intervention in the control group	Exercise intensity	Frequency	Time	Exercise cycle	Measure tools
Zhou (2021)	China	90 (45/45)	Pregnant women with anxiety or depression (26–29 weeks gestation)	Prenatal intervention	Positive thinking yoga (Group exercise + Individual exercise at home)	Pregnancy education + psychological interventions	Low	Group exercise: 1 time/week; Individual exercise at home: 1 time/day	Group exercises: 90 min/time; Individual exercises at home: 30 min/time	6 weeks	SDS, SAS

BDI-II, Beck depression inventory—II; CES-D, Center for Epidemiologic Studies Depression Scale; DASS-42, Depression Anxiety Stress Scale; EPDS, Edinburgh Postnatal Depression Scale; FIF, Fatigue Identification Form; FAI, Fatigue Assessment Instrument; FSC, Fatigue Symptom Checklist; HAD, Hospital Anxiety Depression Scale; HDRS, Hamilton Depression Rating Scale; HARS, Hamilton Anxiety Rating Scale; IDAS, Inventory of Depression and Anxiety Symptoms; MFI-20, Multidimensional Fatigue Inventory; PFS, Postpartum Fatigue Scale; POMS, Profile of Mood States Questionnaire; S-AI, State Anxiety Inventory; SAS, Self-rating Anxiety Scale; SDS, Self-rating Depression Scale; STAI, State–trait anxiety inventory; WHOQOL, World Health Organization Quality of Life-BREF scale; SF-36, the 36-item Short Form Health Survey.

3.5 Sensitivity analysis

Sensitivity analyses were performed for each of the 3 indicators included literature, to evaluate the reliability by excluding literature one by one. No significant differences were found in the results, indicating that the results of this meta-analysis are credible (Figure 4).

3.6 Meta-analysis results

3.6.1 Depression indicators

A total of 30 literatures with 2,473 subjects were included, with a total sample size of 1,253 in the experimental group and 1,220 in the control group. The overall heterogeneity test (I^2 = 85.14%, $p = 0.00$) indicated that there was heterogeneity among multiple studies, so using the random effects model to combined effect sizes: [$g = -0.71$, 95% CI (−0.93, −0.49), $p = 0.00$], was statistically significant (Figure 5A). It showed that exercise can improve maternal depression symptoms with a medium effect.

3.6.2 Anxiety indicators

A total of 17 literatures with 1,481 subjects were included, with a total sample size of 734 cases in the experimental group and 747 cases in the control group. The overall heterogeneity test (I^2 = 88.44%, $p = 0.00$) indicated that there was heterogeneity among multiple studies, so using the random effects model to combine the effect sizes: [$g = -1.09$, 95% CI (−1.42, −0.76), $p = 0.00$], was statistically significant (Figure 5B). It showed that exercise can improve maternal anxiety symptoms with a significant effect.

3.6.3 Fatigue indicators

A total of 9 literatures with 874 subjects were included, with a total sample size of 449 cases in the experimental group and 425 cases in the control group. The overall heterogeneity test (I^2 = 63.99%, $p = 0.01$) indicated that there was heterogeneity among multiple studies, so using the random effects model to combine the effect sizes: [$g = -0.64$, 95% CI (−0.88, −0.40), $p = 0.00$], was statistically significant (Figure 5C). It showed that exercise can improve maternal fatigue symptoms with a medium effect.

3.7 Subgroup analysis of moderators

In this study, exercises content, single exercise time, exercise frequency, exercise cycle, exercise intensity, exercise format and intervention period were set subgroups, respectively, analyzed (Table 2). To explore the sources of heterogeneity and to propose the best exercise intervention program.

3.7.1 Depression indicators

Subgroup analyses of the included literatures of depression indicators showed statistically significant maximum effect sizes in the subgroups of exercise content, single exercise time, exercise frequency, exercise cycle, exercise intensity, exercise format, and intervention period from: yoga ($g = -1.00$, $p = 0.00$), 40–60 min/time ($g = -0.82$, $p = 0.00$), 4–5 times/week ($g = -1.42$, $p = 0.00$), 4–8 weeks ($g = -1.24$, $p = 0.00$), low-medium intensity ($g = -1.04$, $p = 0.002$), group + individual format ($g = -0.86$, $p = 0.039$), postpartum intervention

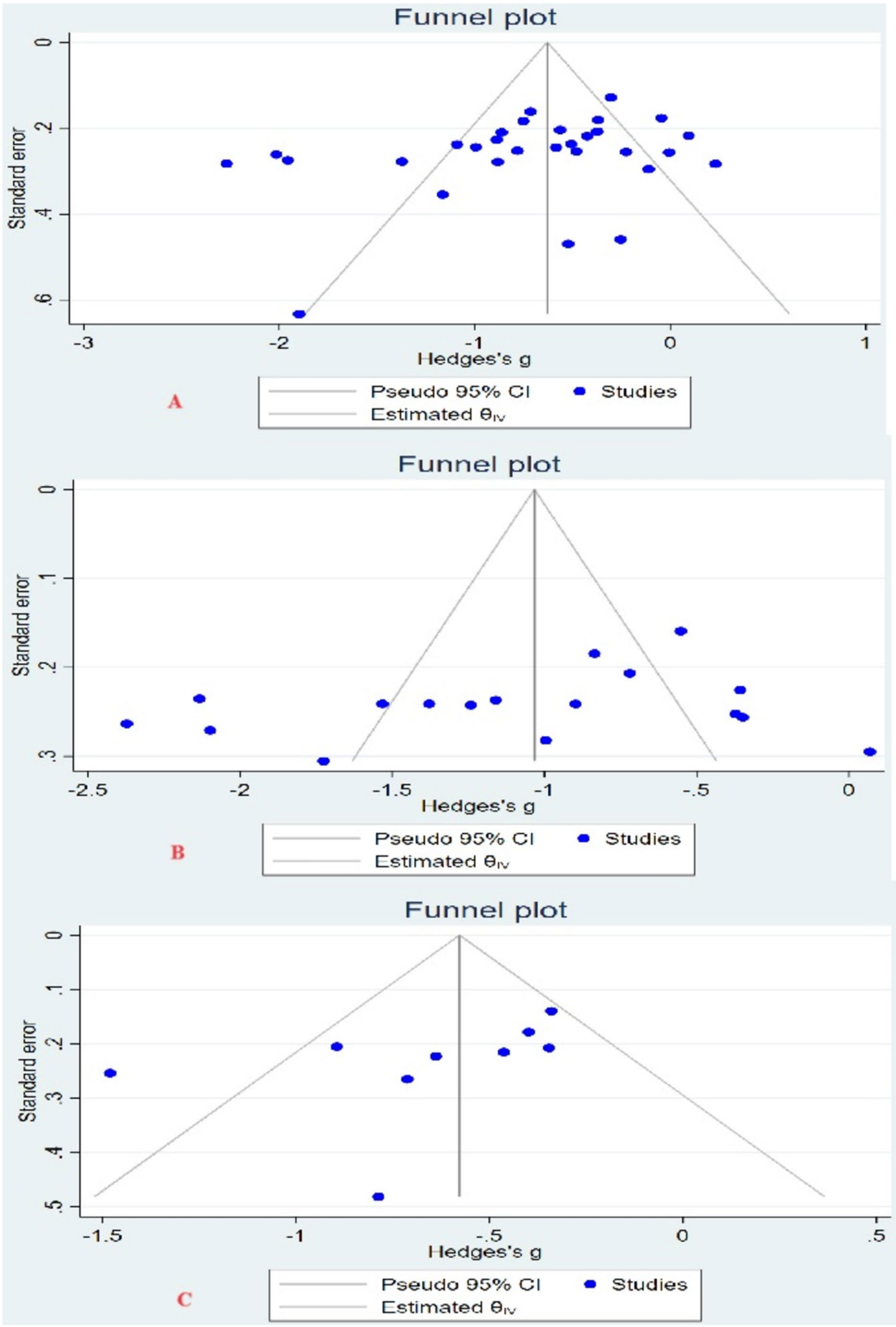

FIGURE 3
Funnel plot. (A) Funnel plot of depression indicators; (B) funnel plot of anxiety indicators; (C) funnel plot of fatigue indicators.

($g=-0.85$, $p=0.00$). Therefore, exercise intervention in the postpartum period, low-moderate intensity yoga with group + individual, 4–5 times/week, 40–60 min/time, duration 4–8 weeks may achieve the best effect in improving maternal depressive symptoms.

3.7.2 Anxiety indicators

Subgroup analyses of the included literatures of anxiety indicators showed statistically significant maximum effect sizes in the subgroups of exercise content, single exercise time, exercise frequency, exercise cycle, exercise intensity, exercise format, and intervention period from: yoga ($g=-1.12$, $p=0.00$), 40–60 min/time ($g=-1.27$, $p=0.00$), 4–5 times/week ($g=-1.10$, $p=0.00$), 4–8 weeks ($g=-1.32$, $p=0.00$), low intensity ($g=-1.26$, $p=0.00$), group + individual format ($g=-2.01$, $p=0.00$), postpartum intervention ($g=-1.29$, $p=0.00$). Therefore, exercise intervention in the postpartum period, low intensity yoga with group + individual, 4–5 times/week, 40–60 min/time, duration 4–8 weeks may achieve the best effect in improving maternal anxiety symptoms.

3.7.3 Fatigue indicators

Subgroup analyses of the included literatures of fatigue indicators showed statistically significant maximum effect sizes in the subgroups

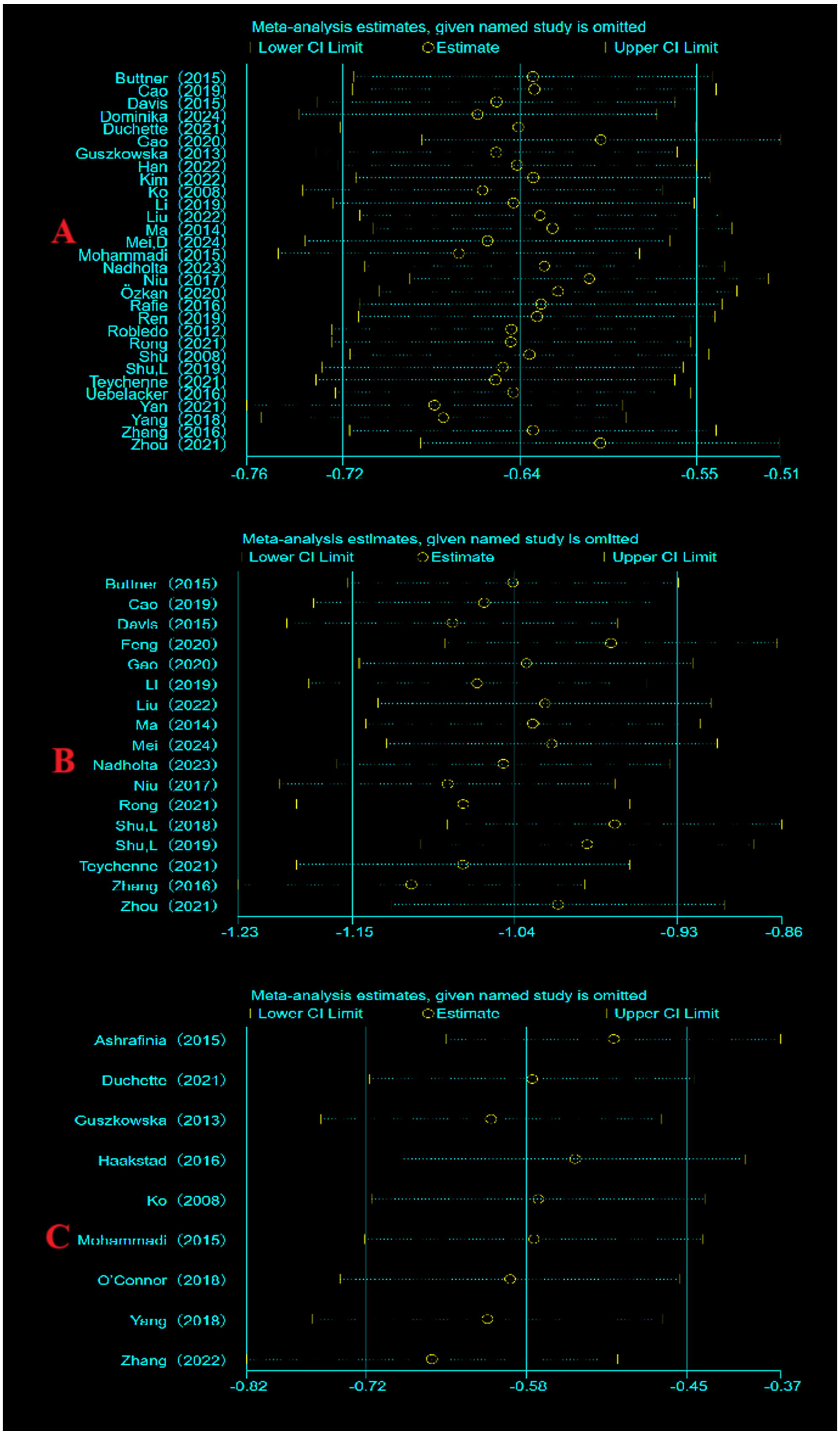

FIGURE 4
Sensitivity analysis. (A) Sensitivity analysis of depression indicators; (B) sensitivity analysis of anxiety indicators; (C) sensitivity analysis of fatigue indicators.

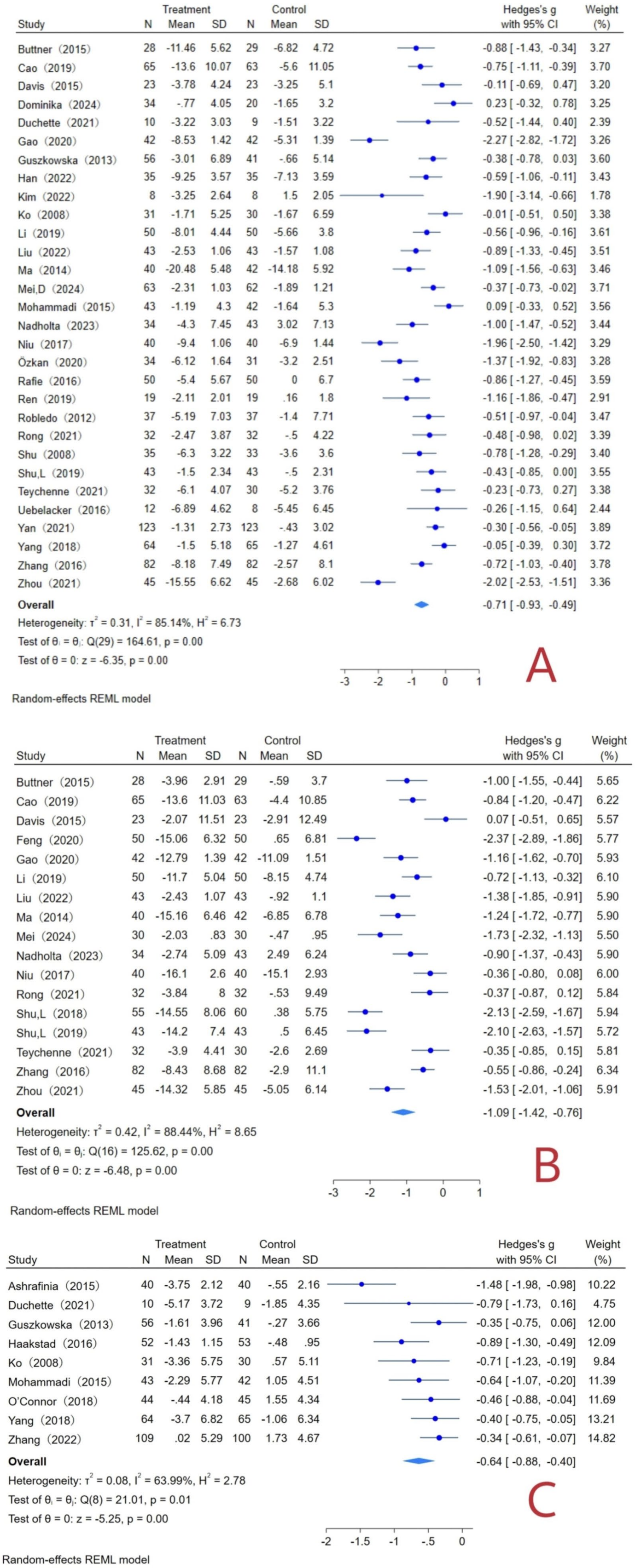

FIGURE 5
Exercise interventions and maternal forest plot. (A) Forest plot of depression indicators; (B) forest plot of anxiety indicators; (C) forest plot of fatigue indicator.

TABLE 2 Analysis of moderating variables.

Moderators	Outcome	Homogeneity test			Category	Number of literatures	Number of samples	Effect size and 95% CI	Two-tailed test	
		Q	p	I^2 (%)					Q	p
Exercise content	Depression	164.61	0.00	85.14	Yoga	13	1,035	−1.00 (−1.36, −0.63)	76.37	0.00
					Combination of aerobic exercise	15	1,361	−0.47 (−0.68, −0.26)	43.62	0.00
					Pilates	2	77	−0.87 (−2.71, 0.98)	7.70	0.359
	Anxiety	125.62	0.00	88.44	Yoga	14	1,231	−1.12 (−1.50, −0.75)	111.89	0.00
					Combination of aerobic exercise	3	250	−0.95 (−1.71, −0.19)	12.03	0.014
	Fatigue	21.01	0.007	63.99	Yoga	1	19	−0.79 (−1.73,0.16)	0.00	0.102
					Combination of aerobic exercise	6	714	−0.49 (−0.66, −0.32)	6.23	0.00
					Pilates	2	141	−1.10 (−1.85, −0.35)	4.39	0.004
Single exercise time	Depression	131.72	0.00	83.20	10–30 min/time	5	493	−0.58 (−1.10, −0.05)	28.83	0.031
					40–60 min/time	17	1,148	−0.82 (−1.13, −0.52)	86.07	0.00
					75–90 min/time	5	495	−0.42 (−0.68, −0.15)	5.45	0.002
	Anxiety	60.69	0.00	83.01	10-30 min/time	3	274	−0.97 (−1.35, −0.59)	7.35	0.00
					40–60 min/time	8	630	−1.27 (−1.79, −0.76)	33.66	0.00
					75–90 min/time	2	210	−0.29 (−0.89,0.31)	3.43	0.342
	Fatigue	21.01	0.007	63.99	10–30 min/time	5	592	−0.64 (−1.02, −0.25)	16.74	0.001
					40–60 min/time	3	263	−0.65 (−0.99, −0.30)	3.63	0.00
					75–90 min/time	1	19	−0.79 (−1.73,0.16)	0.00	0.102
Exercise frequency	Depression	131.28	0.00	83.98	1–2 times/week	12	1,052	−0.69 (−0.99, −0.39)	42.41	0.00
					3 times/week	10	743	−0.40 (−0.66, −0.13)	30.64	0.004
					4–5 times/week	4	308	−1.42 (−1.98, −0.86)	13.87	0.00
	Anxiety	60.69	0.00	83.01	1–2 times/week	7	619	−0.86 (−1.37, −0.34)	44.35	0.001
					3 times/week	3	252	−0.96 (−1.71, −0.21)	11.78	0.012
					4–5 times/week	3	243	−1.10 (−1.37, −0.83)	1.11	0.00
	Fatigue	21.01	0.007	63.99	1–2 times/week	4	310	−0.59 (−0.89, −0.29)	4.11	0.00
					3 times/week	3	275	−0.54 (−0.78, −0.30)	1.25	0.00
					4–5 times/week	2	289	−0.89 (−2.01,0.23)	15.50	0.118

(Continued)

TABLE 2 (Continued)

Moderators	Outcome	Homogeneity test			Category	Number of literatures	Number of samples	Effect size and 95% CI	Two-tailed test	
		Q	p	I^2 (%)					Q	p
Exercise cycle	Depression	144.63	0.00	83.78	4–8 weeks	14	903	−0.85 (−1.24, −0.46)	94.87	0.00
					9–12 weeks	12	849	−0.64 (−0.94, −0.35)	43.65	0.00
					14–16 weeks	2	205	−0.84 (−1.13, −0.55)	0.64	0.00
	Anxiety	125.62	0.00	88.44	4–8 weeks	6	1,070	−1.32 (−1.72, −0.92)	92.86	0.00
					9–12 weeks	6	206	−0.36 (−0.64, −0.08)	0.00	0.011
					14–16 weeks	2	205	−0.86 (−1.15, −0.57)	0.04	0.00
	Fatigue	20.93	0.00	69.04	4–8 weeks	4	447	−0.70 (−1.21, −0.18)	17.03	0.008
					9–12 weeks	4	342	−0.59 (−0.87, −0.32)	3.88	0.00
Exercise intensity	Depression	164.61	0.00	85.14	Low	13	911	−0.69 (−1.03, −0.36)	61.36	0.00
					Medium	7	511	−0.63 (−1.00, −0.25)	25.24	0.001
					Low-medium	6	693	−1.04 (−1.71, −0.37)	64.86	0.002
					Medium-high	4	298	−0.46 (−0.90, −0.02)	9.80	0.041
	Anxiety	125.62	0.00	88.44	Low	11	941	−1.26 (−1.72, −0.79)	99.37	0.00
					Medium	2	190	−0.63 (−1.10, −0.15)	2.38	0.01
					Low-medium	4	350	−0.90 (−1.34, −0.45)	11.66	0.00
	Fatigue	21.01	0.007	63.99	Low	4	289	−0.83 (−1.34, −0.33)	12.22	0.001
					Medium	1	85	−0.64 (−1.08, −0.20)	0.00	0.004
					Low-medium	4	500	−0.49 (−0.75, −0.24)	5.51	0.00
Exercise format	Depression	164.61	0.00	85.14	Group	15	1,117	−0.65 (−0.93, −0.37)	63.55	0.00
					Individual	11	872	−0.76 (−1.15, −0.37)	65.28	0.00
					Group + individual	4	424	−0.86 (−1.66, −0.05)	35.70	0.039
	Anxiety	125.62	0.00	88.44	Group	9	743	−0.97 (−1.40, −0.54)	50.92	0.00
					Individual	5	433	−0.77 (−1.13, −0.40)	12.85	0.00
					Group + individual	3	305	−2.01 (−2.49, −1.52)	6.09	0.00
	Fatigue	21.01	0.007	63.99	Group	4	352	−0.6(−1.12, −0.27)	16.80	0.00
					Individual	5	522	−0.60 (−0.86, −0.34)	4.15	0.001

(Continued)

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TABLE 2 (Continued)

Moderators	Outcome	Homogeneity test			Category	Number of literatures	Number of samples	Effect size and 95% CI	Two-tailed test	
		Q	p	I^2 (%)					Q	p
Intervention period	Depression	164.61	0.00	85.14	Prenatal	13	847	−0.66 (−0.98, −0.34)	52.03	0.00
					Postpartum	15	1,235	−0.85 (−1.17, −0.53)	91.73	0.00
					Prenatal+ Postpartum	2	331	−0.15 (−0.53,0.24)	2.48	0.458
	Anxiety	125.62	0.00	88.44	Prenatal	9	802	−0.88 (−1.14, −0.61)	18.39	0.00
					Postpartum	8	679	−1.29 (−1.86, −0.72)	98.85	0.00
	Fatigue	21.01	0.007	63.99	Prenatal	5	519	−0.51 (−0.75, −0.27)	5.92	0.00
					Postpartum	3	270	−0.85 (−1.48, −0.21)	12.21	0.009
					Prenatal+ Postpartum	1	85	−0.64 (−1.08, −0.20)	0.00	0.004

of exercise content, single exercise time, exercise frequency, exercise cycle, exercise intensity, exercise format, and intervention period from: Pilates ($g=-1.10$, $p=0.004$), 40–60 min/time ($g=-0.65$, $p=0.00$), 1–2 times/week ($g=-0.59$, $p=0.00$), 4–8 weeks ($g=-0.70$, $p=0.008$), low intensity ($g=-0.83$, $p=0.001$), group format ($g=-0.69$, $p=0.00$), postpartum intervention ($g=-0.85$, $p=0.009$). Therefore, exercise intervention in the postpartum period, low intensity yoga with group, 1–2 times/week, 40–60 min/time, duration 4–8 weeks may achieve the best effect in improving maternal fatigue symptoms.

4 Discussion

4.1 Quality assessment of the included literature

There was no harmonized measure tools used in the literature included for the 3 indicators, with a total of 7 different tools used for the depression indicator, 8 different tools used for the anxiety indicator, and 7 different tools used for the fatigue indicator. The lack of harmonized measure tools to assess maternal symptoms of depression, anxiety, and fatigue may be one of the reasons for the high level of heterogeneity.

None of the included literature was blinded to the subjects and experiment conductors, which affected the quality of the literature, but did not affect the effectiveness of the exercise intervention on maternal depression, anxiety and fatigue. Because of the specificity of the maternal population and the nature of the exercise intervention, it was beneficial for subjects and implementers to understand the purpose of the experiment. Therefore, not blinding subjects and implementers did not affect the results of the experiment.

4.2 Analysis of overall effect

The results of our study are consistent with previous research (Cai et al., 2022; Ji et al., 2024; Liu et al., 2020), that maternal can benefit from exercise and significant improvements in depression, anxiety and fatigue. Research suggests that exercise may be a potential alternative to antidepressant and anxiolytic medications and has a proximate effect to pharmacologic interventions in alleviating depression and anxiety symptoms (Guerrera et al., 2020; Fox et al., 2023). However, as pharmacologic interventions may cause some degree of maternal side effects (Marasine et al., 2020), women are reluctant to take medications, resulting in low compliance (Zhao et al., 2020). Therefore, exercise may be a safer and more effective intervention to improve maternal depression and anxiety. Exercise improves maternal depression, anxiety, and fatigue in 3 main ways: social support during exercise, positive experiences of exercise, and physiologic changes in the body produced by exercise (Jia et al., 2018). First, in terms of physiological regulation, exercise can elevate the level of neurotrophic factors in the body, improve neurotransmitter expression and other endocrine regulatory mechanisms, thus intervening maternal depression and anxiety (Li and Gao, 2019). Furthermore, it can treat depression, anxiety and mental fatigue by remodeling brain structure, activating brain targets, maintaining the volume of the prefrontal cortex and hippocampus, improving mood and releasing psychological stress (Thomas et al., 2016; Maass et al., 2015). Secondly, body shape changes, weakened mobility and lifestyle variations are important causes of maternal depression, anxiety and fatigue (Badr and Zauszniewski, 2017; Doering Runquist et al., 2009). Exercise can promote the recovery of maternal body functions and image, regulate the psychological state, and quickly adapt to the change of their own social roles, which in turn can effectively improve maternal depression and anxiety (Bershadsky et al., 2014). The recovery of physical function can help to improve maternal anti-fatigue ability and improve fatigue symptoms (Liu et al., 2020). Compared to cognitive-behavioral treatments and other interventions, exercise interventions have a strong potential advantage (van Lieshout et al., 2021), with social support and positive experiences for maternal in exercise and are more accessible and cost-effective for women who have low income, learning comprehension difficulties, and lower levels of education (Hedman-Lagerlöf et al., 2021). Despite the many benefits of exercise intervention, it is not suitable for all maternal. Exercise is not suitable for women with gestational hypertension, placenta previa, and conditions such as a weakened thyroid gland, or women who have delivered by cesarean section for less than 6 weeks (Corwin and Arbour, 2007; Hinman et al., 2015). Therefore, before exercise begins, clinicians should assess maternal fitness to ensure the safety of the exercise intervention.

4.3 Exercise content

In the depression and anxiety indicators, the results of the subgroup analyses of exercise content were consistent, yoga had the best intervention effect. In the fatigue indicator, Pilates had the best intervention effect. Yoga and Pilates are popular in the maternal population and have high reliability and satisfaction in improving maternal depression, anxiety, and fatigue (Nadholta et al., 2023; Ashrafinia et al., 2015). Yoga and Pilates mainly consist of breathing exercises, body posture adjustments, meditation, stretching, and relaxation exercises (Rong et al., 2021). Yoga can reduce depression, anxiety, and labor pain throughout pregnancy, enhance immunity, and improve mental health (Field et al., 2012). Meditation practice in yoga can improve maternal concentration, exclude the interference of the external environment, make their mood calmer and more relaxed (Campbell and Nolan, 2016), improve the sense of self-efficacy of pregnant women in childbirth, enhance confidence in childbirth, and help to alleviate the depression, anxiety and physiological discomfort of childbirth (Tilden et al., 2016). For postpartum women, yoga can help them improve their physical form and achieve improvement in postpartum depression and anxiety (Li and Gao, 2019). Pilates has a positive impact on physical and mental health and is considered an effective measure for intervention and treatment of maternal fatigue (Ko et al., 2008). The stretching exercises in Pilates help to improve maternal flexibility and joint flexibility, which play a role in improving self-care, increasing the level of daily activities and relieving low back pain, which achieves the effect of relieving the symptoms of maternal fatigue (Ashrafinia et al., 2015).

4.4 Time, frequency, cycle, intensity and format of exercise

Our study showed that subgroup analyses of the 3 indicators regarding single exercise time and exercise cycle were consistent, 40–60 min/time, 4–8 weeks have the best intervention effect. Shorter exercise time may limit accurate assessment and fail to ensure long-term gains. Longer time can aggravate the physical and psychological burden on the maternal body and even trigger a range of inferiority (Dipietro et al., 2019). In addition, the American College of Obstetricians and Gynecologists (ACOG) recommends that single exercise time of 30 min or more and more than 150 min per week are more effective, which is consistent with our study results (Feng et al., 2019). During pregnancy, prolonged exercise may lead to miscarriage due to embryonic instability and other reasons; after delivery, excessive exercise may cause harm to the maternal body due to temporary mobility problems (Liu et al., 2023). Therefore, longer cycle exercise interventions may not be appropriate for maternal. Research pointed out that the exercise cycle of 4-8 weeks can not only achieve a good intervention effect, but also enable pregnant women to develop the habit of exercise, which is a more appropriate exercise cycle (Liu et al., 2020).

Exercise frequency is an important factor influencing the effectiveness of the intervention. The results of this study showed that 4–5 times/week was the best intervention for depression and anxiety. 1–2 times/week was the best intervention for fatigue. Maternal depression and anxiety symptoms declined with increased exercise frequency, and there was a negative correlation between them (Jia et al., 2021). Furthermore, the recommendations of ACOG provide support for this research's findings (Feng et al., 2019). The subgroup analysis of fatigue indicators was inconsistent, probably because low-frequency exercise is more conducive to relieving maternal low back pain, relaxing the body and mind, and does not aggravate physical and mental stress and burden, which is more effective in improving maternal fatigue (Liu et al., 2024).

Exercise intensity plays an important role in improving depression, anxiety, and fatigue symptoms, but information on best exercise intensity is still limited and needs to be further explored. The results of this study showed that Low intensity was the best intervention for anxiety and fatigue, and Low-medium intensity was the best intervention for depression. Although the results were inconsistent, they further validated the effectiveness of Low intensity. For maternal, exercise intensity should be Low intensity or Low-medium intensity to avoid high intensity exercise causing harm to both the mother and the fetus (Sánchez-Polán et al., 2021). Research has shown that low or medium intensity aerobic exercise is a recognized exercise intensity that not only protects maternal cardiovascular function, but also does not exacerbate post-exercise fatigue (Cai et al., 2022; Dipietro et al., 2019).

In this study, group + individual format was the best intervention for depression and anxiety, and group format was the best intervention for fatigue. Group-based exercise can give full play to face-to-face supervision, which can enhance compliance, and the effectiveness of interventions compared with unsupervised exercise (Liu et al., 2019). In addition, group exercise can help maternal gain more social support from peers and coaches, which, along with professional guidance from coaches and supervision from clinicians, greatly enhances the safety of the exercise (Liu et al., 2023). But group exercise requires adequate space and a high level of organizational skills on the part of the organizer to coordinate the time and place of all participants. Individual exercise is not limited by time and place, which can enhance maternal subjectivity and freedom (Zhang et al., 2019). For healthcare organizations with limited resources, combining group and individual exercise may be a better choice, but movement instruction and safety preaching should be done before individual exercise.

4.5 Intervention period

The results of the subgroup analyses on the intervention period in the 3 indicators were consistent, postpartum intervention was the best effect. Pregnant women's perception of exercise is more scarce, they believe that exercise during pregnancy is not safe, so they rarely exercise to avoid harm to the fetus (Liu et al., 2020). After childbirth, the sudden shift in women's social identity, changes in body shape, and decreased sleep quality due to caring for the baby may lead to more severe symptoms of depression, anxiety, and fatigue than in the prenatal period (Ji et al., 2024; Iwata et al., 2018). Compared with exercise during pregnancy, postpartum intervention may be more effective (Li and Gao, 2019), and the fact that postpartum exercise is more safe and convenient and mothers no longer have to worry about the adverse effects of exercise on the fetus, it's may be one of the reasons why postpartum intervention is better than prenatal intervention (Dipietro et al., 2019).

4.6 Comparison with previously published meta-analyses

Although this meta-analysis is consistent with the results of most of the existing literature that validate the effectiveness of exercise intervention on maternal depression, anxiety and fatigue. However, compared to other research, this review excluded combined interventions, only analyzed exercise intervention, and included all exercise types, which is more helpful in evaluating the final effect of exercise, and the results have a higher reliability. This review focuses on introducing refined subgroup analyses to dissect the effects of exercise content, single exercise time, exercise frequency, exercise cycle, exercise intensity, exercise format, and intervention period on maternal depression, anxiety, and fatigue, which have not been extensively explored in previous meta-analyses, and which may provide more specificity for the implementation or development of exercise intervention programs.

4.7 Limitations and perspectives

There are some limitations in our study, which we hope to further improve in future research and practice. First, although most trials have reported positive effects of exercise interventions on maternal depression, anxiety, and fatigue, the same exercise intervention program may have different effects on maternal women with different levels of depression, anxiety, and fatigue (e.g., mild, moderate, severe). Researchers should explore more refined and appropriate exercise intervention protocols based on different levels of maternal depression, anxiety, and fatigue to seek continuous optimization of intervention effects. Second, none of the subjects in the included literature had any diseases or comorbidities; therefore, the results of this study may not be appropriate for all maternal. Researchers should clearly define the maternal population that is suitable to participate in exercise, which could be effective in improving the safety of exercise intervention. For maternal who have diseases or complications but can still participate exercise, researchers should explore suitable exercise programs and pay more attention to exercise frequency, exercise cycle, and exercise intensity factors in the exercise program. Thirdly, while this study suggests the best exercise content, exercise intensity and exercise frequency, etc., these factors are key information for precise interventions. However, the current evidence in this area is not sufficient. Researchers should conduct more high-quality experiments to determine the best exercise content, exercise intensity and exercise frequency, etc., which can help to develop a more standardized exercise intervention program. Fourth, the included literature did not use a harmonized measurement tool, which may have been heterogeneous. Researchers should develop harmonized measurement tools to address the specificities of the maternal population to improve the accuracy of the assessment. Fifth, due to the specificity of the maternal population and the nature of the exercise intervention, blinding was not implemented during the experiment, which had a certain risk of bias and affected the quality assessment results to a certain extent. Researchers should strictly follow the guidelines for randomized controlled trials to ensure the reliability of the results.

5 Conclusions and recommendations

Our meta-analysis suggests that exercise can effectively improve maternal depression, anxiety and fatigue symptoms. Postnatal intervention may be more effective than prenatal intervention. Low-moderate intensity yoga with group + individual, 4–5 times/week, 40–60 min/time, duration 4–8 weeks is more effective in improving depressive symptoms; Low intensity yoga with group + individual, 4–5 times/week, 40–60 min/time, duration 4–8 weeks is more effective in improving anxiety symptoms; Low intensity Pilates with group, 1–2 times/week, 40–60 min/time, duration 4–8 weeks is more effective in improving fatigue symptoms. Despite the promising findings, there is less research on exercise intervention programs and more research is needed to support these findings.

Clinicians should consider factors such as exercise content, frequency and intensity when developing an exercise intervention program, and can use the results of this study as a reference. For example, it is more appropriate to choose light exercise such as yoga or Pilates, to take group exercise with low or moderate intensity, and to choose an intervention cycle of 4–8 weeks, 1–5 times/week, 40–60 min/time. Second, the group exercise movement process should ensure that the movements are standardized to avoid any other repercussions due to irregular movements. Choosing group + individual exercise may be a better option for healthcare organizations with limited resources, but it is important to provide movement instructions and safety presentations in advance. Finally, the monitoring of the exercise intervention process should be strengthened by measuring maternal heart rate and subjective perception at regular intervals during exercise to maximize the avoidance of exercise risks for maternal.

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 authors.

Author contributions

HY: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. QM: Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. XL: Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. SC: Writing – original draft, Validation, Software, Investigation, Formal analysis, Data curation. HH: Writing – original draft, Validation, Software, Investigation, Formal analysis, Data curation.

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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

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