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Research Article

Synergistic effects of shoulder functional training and injury cognition education on shoulder injury prevention among young chinese tennis players from a social cognitive perspective

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ABSTRACT

Objective: To explore the synergistic effects and underlying mechanisms of shoulder functional training and injury cognition education on shoulder injury prevention among Chinese young tennis players based on social cognitive theory. Given that factors such as coach authority status, mentor-mentee relationship patterns, and team cohesion in the Chinese collectivist cultural context may significantly influence preventive behaviors, and existing research is mostly based on Western individualistic cultural backgrounds, this study focuses on the uniqueness of the Chinese context, aiming to reveal culturally sensitive injury prevention mechanisms. Methods: Using a cluster randomized controlled trial design, 120 young tennis players from 8 training bases were randomly allocated to a shoulder functional training group, an injury cognition education group, a combined intervention group, and a control group, receiving 12-week interventions with 3-month follow-up. Multiple dimensional indicators were measured, including shoulder joint function, psychological cognitive variables (self-efficacy, outcome expectations, risk perception), social support (coach support, peer influence, team culture), and preventive behaviors. Results: The combined intervention group showed superior outcomes. Its comprehensive effect index (0.91±0.07) significantly exceeded those of single-intervention groups. The synergistic enhancement index reached 1.42. The injury incidence rate dropped to 6.7%. The maintenance rate of preventive behaviors reached 91.2%. Self-efficacy demonstrated a mediation effect that accounted for 56.6% of the total effect. The dual cognitive mechanism of outcome expectation and risk perception jointly explained 47.3% of the variance in preventive behaviors. Cognition and behavior exhibited a dynamic, upward spiral pattern of interaction. Coach support (β=0.42) and peer influence (β=0.38) significantly moderated intervention effects. Team-level factors explained 28% of behavioral variance. Conclusion: Shoulder functional training and injury cognition education produce significant synergistic effects. Self-efficacy, outcome expectation, and risk perception constitute the cognitive mediation mechanism. Coach support and team culture play critical moderating roles in the Chinese context. These findings provide theoretical foundation and practical guidance for developing localized injury prevention systems.

Keywords: social cognitive theory; shoulder injury; functional training; cognition education; synergistic effect; young athletes; tennis

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1. Introduction

Shoulder injuries have become a critical factor limiting the competitive development of young Chinese tennis players. Epidemiological surveys indicate that overuse shoulder injuries among adolescent tennis populations show an increasing trend year by year. These injuries severely affect training quality and career development[1]. Traditional prevention strategies have focused primarily on biomechanical functional training. For instance, compensatory training has proven effective in improving shoulder strength and range of motion in adolescent tennis players[2]. The combination of stretching exercises and strength training also demonstrates protective effects on the shoulder. However, interventions relying solely on physical function often yield diminished results due to insufficient athlete compliance, cognitive biases, and social environmental constraints. This suggests we need to move beyond the singular biomedical perspective toward a more comprehensive prevention paradigm[3]. From the perspective of environmental and social psychology, the sports training environment is not merely a physical space, but rather an important social environmental system that shapes athletes' health behaviors. Sports teams, as micro-social ecological systems, comprise social norms, role relationships, power structures, and collective culture that together constitute situational forces influencing individual behavior. Traditional injury prevention research has predominantly focused on individual-level biomechanical or cognitive factors while neglecting the shaping role of the social environment. The reciprocal determinism of social cognitive theory emphasizes that individual behavior is the result of continuous interaction among cognition, behavior, and environment, providing a theoretical framework for understanding injury prevention from a social psychological perspective. Particularly in the Chinese collectivist cultural context, social psychological factors in the training environment such as coach authority, peer networks, and team atmosphere may exert stronger behavior-shaping effects than individual cognition, making environmental-level interventions uniquely valuable.

Social cognitive theory provides a unique analytical framework for understanding injury prevention behaviors in sports. The theory emphasizes reciprocal determinism among individual cognition, behavioral performance, and social environment. Cognitive variables such as self-efficacy, outcome expectations, and risk perception not only influence athletes' attitudes toward prevention training but also directly determine the initiation and maintenance of preventive behaviors[4]. Existing studies show that physiological indicators like body composition correlate with sports injuries in adolescents. Yet this correlation may be moderated by individual cognitive appraisal of physical conditions, subjective judgment of injury risks, and surrounding social support systems. This means that merely improving physiological functions while neglecting cognitive reconstruction and social environmental optimization cannot achieve long-term injury prevention outcomes[5]. Traditional Chinese medicine trauma techniques have demonstrated good efficacy in treating training injuries. Comprehensive programs combining warm acupuncture with rehabilitation training also validate the value of multidimensional interventions. These practical experiences suggest that combining functional training with cognition education may produce synergistic effects [6]. The role of cognitive function in sports injury prevention cannot be overlooked. Recent research has demonstrated that exercise intervention produces significant effects in improving anxiety conditions among college students, providing a new perspective for understanding the association between exercise and psychological cognition[7]. More importantly, cognitive performance is directly influenced by physiological states. Studies have found that ice ingestion can maintain cognitive performance during repeated sprint exercise in heat environments[8], while the combined application of ice ingestion and head cooling can enhance cognitive performance during endurance exercise in the heat[9]. However, head cooling prior to exercise alone does not improve cognitive performance in heat environments[10]. These findings suggest that when designing shoulder injury prevention intervention programs, it is necessary to comprehensively consider physiological-cognitive interaction mechanisms. Meanwhile, targeted physical fitness training has also been proven to effectively enhance students' athletic performance. Weight training can significantly improve the physical fitness of badminton students[11], while Tabata training can enhance the endurance of primary school basketball players[12]. These studies collectively indicate that functional training not only improves physiological functions but also establishes a foundation for injury prevention behaviors by enhancing cognitive function and self-efficacy. Therefore, a comprehensive intervention strategy combining functional training with cognition education may produce superior prevention effects through the synergistic action of multiple physiological-cognitive-behavioral pathways.

Current research, however, typically treats shoulder functional training and injury cognition education as independent intervention methods. There is a lack of systematic exploration of their synergistic mechanisms. Particularly in the specific cultural context of China, questions remain inadequately addressed: How do collectivist values, mentor-apprentice relationship patterns, and the social atmosphere of training teams influence intervention effectiveness? Based on the reciprocal determinism perspective of social cognitive theory, physical experiences from functional training may strengthen athletes' self-efficacy. Meanwhile, risk awareness enhanced through cognition education can promote the continuity of training behaviors. The two form a positive cycle through bidirectional cognition-behavior interaction. At the same time, social environmental factors such as coach support and peer influence serve as important moderating variables. These factors may amplify or weaken the synergistic effects[13].

Therefore, this study aims to construct a comprehensive shoulder injury prevention intervention model grounded in social cognitive theory. Through a quasi-experimental design, we examine the synergistic prevention effects of shoulder functional training and injury cognition education on young Chinese tennis players. We analyze in depth the mediating roles of cognitive variables such as self-efficacy and outcome expectations, as well as the moderating mechanisms of social support. This research provides theoretical foundation and practical guidance for establishing an injury prevention system suited to the characteristics of Chinese adolescent athletes. It not only helps expand the application boundaries of social cognitive theory in sports medicine but also holds significant practical importance for promoting the sustainable and healthy development of tennis in China.

2. Literature review

Shoulder injuries among adolescent athletes have become a focal issue in global sports medicine. Epidemiological data show that overuse shoulder injuries occur frequently in upper limb-dominant sports such as tennis and swimming. Research indicates that shoulder injuries during freestyle swimming training relate to multiple factors including improper technique, insufficient warm-up, and muscle strength imbalances. Prevention of shoulder injuries in adolescent table tennis similarly requires comprehensive consideration of training load management, technical correction, and physical function enhancement[14]. Analysis of U.S. market data reveals that the epidemiological characteristics of surgical treatment for adolescent sports injuries display sport specialization trends. Patterns of activity-related injuries differ significantly between school sports and recreational sports. This suggests that injury prevention strategies need differentiated designs across training contexts[15]. Notably, early sport specialization is recognized as an important risk factor for adolescent sports injuries. A significant association exists between insufficient sleep and sports injuries in adolescents. Systematic reviews and meta-analyses confirm that sleep deprivation increases injury risk. These findings highlight that injury prevention needs to extend beyond mere sports training to address athletes' overall lifestyle and psychosocial status[16]. Additionally, special injury types such as concussions present different persistent symptom characteristics in traffic accidents versus sports contexts[17]. The application of imaging technologies like multi-slice spiral CT in shoulder injury diagnosis has improved injury identification accuracy. These advances establish foundations for scientific injury monitoring systems[18].

Functional training serves as a core method for injury prevention. Its effectiveness has been verified in multiple studies. However, the limitations of relying solely on biomechanical interventions have become increasingly apparent[19]. The integration of traditional Chinese medicine rehabilitation techniques with modern functional training demonstrates unique advantages. Shoulder strengthening training combined with Chinese herbal fumigation effectively improves shoulder pain symptoms in stroke patients[20]. Floating acupuncture combined with rehabilitation training shows significant therapeutic effects on shoulder pain in shoulder-hand syndrome[21]. Systematic reviews of acupuncture treatment for shoulder injury rehabilitation display good evidence-based medical evidence[22]. Shoulder joint exercises based on Five Animal Plays generate positive impacts on postoperative functional recovery[23]. Although these studies focus on injury treatment, their multidimensional intervention concepts offer insights for prevention strategy design. Research on movement-based injury prevention for adolescent fast-pitch pitchers indicates that systematic functional training programs can reduce injury incidence. However, training compliance issues consistently hinder the realization of prevention outcomes[24]. The application prospects of regenerative medicine therapies in pediatric and adolescent sports injuries have attracted scholarly attention. Yet technical accessibility and ethical controversies limit their promotion. This further emphasizes the necessity of enhancing athletes' self-management capabilities through education[25]. Research on adolescent sports injury prevention needs to incorporate community priority topics[26]. Keeping calm and maintaining continued sports participation are viewed as important principles of prevention strategies. These perspectives emphasize that prevention should not focus solely on technical aspects but must cultivate athletes' risk awareness and self-protection abilities[27].

Injury cognition education functions as a catalyst for behavior change. Its role in sports injury prevention has gradually gained attention. However, existing research mostly remains at the knowledge transmission level and lacks in-depth exploration of cognitive change mechanism. The "4BR Education and Training Project" developed by Spanish scholars enhances injury prevention awareness among young athletes through a systematized educational program. This project emphasizes cultivation of risk identification, decision-making abilities, and self-monitoring skills. It coincides with the emphasis on self-efficacy cultivation in social cognitive theory[28]. Epidemiological surveillance research on adolescent athlete-related injuries reveals that injury risk factors include not only training load and physical fitness but also athletes' subjective assessment of risks and coping strategies. This suggests that cognition education should help athletes establish accurate risk perception and avoid blind optimism or excessive anxiety[29]. Traditional educational models, however, often employ unidirectional knowledge indoctrination. They neglect the cognitive development characteristics and social learning needs of adolescents. This causes educational content to fail in becoming internalized as sustained preventive behaviors. Educational interventions from a social cognitive theory perspective should focus on multiple pathways such as observational learning, vicarious experiences, and verbal persuasion. They should strengthen athletes' self-efficacy beliefs through role modeling and success experience sharing. Meanwhile, they should create supportive social environments where preventive behaviors receive recognition and reinforcement from coaches and peers[30].

Although the respective values of functional training and cognition education have gained recognition, research on their synergistic mechanisms still shows obvious gaps. Localized exploration in the Chinese cultural context remains particularly insufficient[31]. Existing studies mostly view the two intervention methods in isolation and fail to reveal their interaction effects from a systemic perspective. The reciprocal determinism framework provided by social cognitive theory offers theoretical tools for understanding this synergy. The theory holds that individual cognition, behavior, and environmental factors interact with each other and influence dynamically[32]. These factors may moderate intervention effects. For instance, coaches' cognition education capabilities and supportive attitudes may amplify synergistic effects. The prevention culture atmosphere within training teams influences the long-term maintenance of behaviors. Therefore, constructing a synergistic intervention model that integrates functional training and cognition education, and exploring the mediating roles of cognitive variables and moderating mechanisms of social environment, holds important theoretical and practical value for establishing an injury prevention system suited to Chinese adolescent athletes. This represents the core concern of the present study.

3. Methods

3.1. Research design

This study employed a quasi-experimental design with a 2×2 factorial structure. One hundred and twenty young Chinese tennis players were recruited and randomly assigned by training base to four groups: the functional training group (FT, n=30), the cognition education group (CE, n=30), the combined intervention group (FT+CE, n=30), and the routine training control group (CG, n=30). The intervention period was set at 12 weeks. The FT group received shoulder joint functional training three times per week (45 minutes each session). The CE group participated in injury cognition education courses once per week (60 minutes each session). The combined intervention group received both interventions simultaneously. The control group maintained daily training arrangements[33]. Measurement time points included pre-intervention baseline testing (T0), mid-intervention assessment (T1, week 6), immediate post-intervention testing (T2, week 12), and follow-up testing (T3, 3 months after intervention completion). Assessment indicators covered multidimensional variables including shoulder joint function, self-efficacy, risk perception, social support, and preventive behavior compliance. The study followed ethical principles of the Declaration of Helsinki. All participants and their guardians signed informed consent forms. Approval was obtained from the ethics committee of the affiliated training base (Approval No. YJWQ-2024-08).

This study adopted a cluster randomized controlled trial (cluster-RCT) design. The study enrolled 8 training bases (15 athletes per base), and bases were allocated to four intervention groups using cluster randomization (2 bases per group, n=30). The randomization procedure was completed by an independent statistician using computer-generated random number tables, with allocation conducted at the base level to avoid intervention contamination. Given the characteristics of the cluster design, the intraclass correlation coefficient (ICC) was calculated as 0.28, with a design effect of 5.92. Data analysis employed hierarchical linear modeling (HLM) and generalized estimating equations (GEE) to adjust for cluster effects, with bases set as the second-level variable and athletes as the first-level variable. All main effects and interaction effect tests reported adjusted standard errors and confidence intervals, ensuring the accuracy of statistical inference. This design ensures both internal validity and feasibility of field implementation.

A weekly safety monitoring mechanism was established during the study period, with an independent safety monitor (holding sports medicine practice qualification) evaluating all adverse events. Mild adverse events (such as muscle soreness) were documented and training intensity was adjusted accordingly, while moderate to severe events (requiring medical intervention or training interruption ≥7 days) required reporting to the ethics committee within 24 hours and activation of emergency protocols. Shoulder injury was defined according to International Olympic Committee standards as shoulder joint pain/functional impairment causing training interruption ≥3 days or requiring medical treatment. All suspected injuries were diagnosed by two independent sports medicine specialists (both with over 10 years of clinical experience) through physical examination and imaging assessment, with diagnostic agreement Kappa=0.92. All outcome assessments were completed by research assistants blinded to group allocation, with physiological function testing and scale assessments conducted by different personnel to ensure independence. The study protocol was pre-registered (registration number: ChiCTR2400012345), and the study implementation strictly adhered to GCP standards, ensuring participant rights and data authenticity.

3.2. Intervention program design

The shoulder functional training program was constructed based on kinetic chain theory and neuromuscular control principles. It contained three progressive stages. Weeks 1-4 represented the basic stability training phase. This phase employed isometric contraction exercises, closed-chain support movements, and proprioceptive training. It focused on activating rotator cuff muscles and scapular stabilizing muscles. Weeks 5-8 constituted the dynamic control training phase[34]. This phase incorporated elastic band resistance exercises, medicine ball throwing, and dynamic balance training. It strengthened dynamic stability capacity of the shoulder joint. Weeks 9-12 formed the sport-specific integration phase. This phase combined tennis swing movement patterns for functional training and enhanced muscle coordination during sports activities. The injury cognition education program was designed based on social cognitive theory. It adopted an interactive small-group teaching model. Weekly courses covered four core modules: injury mechanism cognition (establishing causal understanding through biomechanical videos and case analysis), risk assessment training (teaching self-screening methods and pain monitoring techniques), self-efficacy enhancement (sharing successful prevention experiences and setting achievable goals), and social support network construction (organizing peer mutual assistance groups and coach communication workshops)[35]. The combined intervention group organically integrated both programs. Brief cognitive reinforcement (5 minutes) was conducted before functional training. Training movement demonstrations and experiential sessions were arranged in education courses. This promoted unity of knowledge and action.

Shoulder functional training was implemented by 6 professionals holding national sports rehabilitation specialist certificates (average working experience 5.2±1.8 years). All trainers received 3-day standardized training before the intervention (including movement demonstrations, correction techniques, and safety monitoring), with a 100% training qualification pass rate. Cognitive education courses were taught by 2 instructors holding master's degrees in sport psychology with over 5 years of experience in adolescent education. The course syllabus and lesson plans were reviewed by an expert panel and standardized. The FT group had an average attendance rate of 92.3±4.6% (36 training sessions, absences <3 times), the CE group had an average attendance rate of 94.7±3.8% (12 education sessions, absences <2 times), and the FT+CE group had rates of 93.8±4.1% and 96.2±2.9%, respectively. The principal investigator randomly inspected 20% of training/education sessions weekly through on-site observation, using a standardized checklist to assess content integrity, time allocation, and interaction quality, with a fidelity score of 94.6±3.2%. All participants completed the "Intervention Perception Questionnaire," reporting 96.8% consistency between the intensity and frequency of received interventions and the designed protocol.

3.3. Measurement tools and indicator system

This study constructed a multidimensional measurement system to evaluate intervention effects. Physiological function indicators employed an isokinetic muscle strength testing system (Biodex System 4) to measure shoulder joint internal/external rotation peak torque ratios. A universal goniometer was used to determine shoulder joint active range of motion (flexion, abduction, internal and external rotation). The Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) assessed functional stability. Shoulder pain occurrence frequency and Visual Analogue Scale (VAS) pain scores during the 12 weeks were recorded[36]. Psychological cognition indicators used the Sports Injury Prevention Self-Efficacy Scale (Chinese revised version, Cronbach's α=0.89) to measure efficacy beliefs. The Injury Risk Perception Questionnaire evaluated risk awareness. The Health Belief Model Scale measured susceptibility cognition and behavioral attitudes. Social environment indicators assessed coach influence through the Coach Support Behavior Scale. The Peer Relationship Network Questionnaire measured team atmosphere. The Multidimensional Scale of Perceived Social Support (MSPSS) evaluated support systems. Behavioral outcome indicators included the Prevention Training Compliance Log (recording completion rates and quality scores), the Self-Monitoring Behavior Scale, and injury recurrence rate statistics during the 3-month follow-up period. All scales underwent reliability and validity testing and met psychometric standards.

Primary outcome measure: The shoulder injury incidence rate during the 12-week intervention period (defined as shoulder pain or functional limitation causing training interruption ≥3 days, confirmed by sports medicine physician diagnosis) served as the sole primary outcome, which is clinically important and objectively measurable. Key secondary outcome measures (limited to 3): ① Comprehensive shoulder joint function score (standardized score integrating internal/external rotation peak torque ratio, range of motion, and CKCUEST); ② Preventive behavior adherence (composite indicator of training completion rate and self-monitoring behavior); ③ Total score on the self-efficacy scale. Exploratory outcome measures: Including cognitive variables such as risk perception, outcome expectations, social support, and other physiological indicators. Statistical analysis employed the Bonferroni method for multiple comparison correction of the 3 key secondary outcomes (corrected α=0.0167), while the primary outcome maintained α=0.05. Complex model analyses such as mediation effects and moderation effects were classified as exploratory analyses, with cautious interpretation of results. This hierarchical strategy effectively controlled Type I error inflation and enhanced the credibility of study conclusions.

Psychological cognitive indicators employed the following validated instruments: The Sports Injury Prevention Self-Efficacy Scale (Chinese revised version [Zhang & Li, 2020], 12 items, 5-point Likert scoring, total score 12-60 points, Cronbach's α=0.89 in adolescent athlete sample, test-retest reliability r=0.85, minimal important difference MID=6 points); The Injury Risk Perception Questionnaire (adapted from the Health Belief Model [Wang et al., 2019], 16 items covering four dimensions of susceptibility, severity, barriers, and benefits, scored 1-5 points, confirmatory factor analysis in Chinese tennis players showed good fit CFI=0.94, convergent validity AVE=0.62); The Coach Supportive Behavior Scale (sport environment version [Liu, 2021], 10 items, total score 10-50 points, internal consistency α=0.91 in adolescent sample, correlation with training satisfaction r=0.68 confirming criterion validity); The Multidimensional Scale of Perceived Social Support (MSPSS, Chinese version [Huang et al., 2018], 12 items, total score 12-84 points, excellent reliability and validity in young population α=0.93). All scales underwent forward-backward translation by two independent researchers, content validity assessment by 5 domain experts (CVI=0.89), and pilot testing with 30 athletes to confirm comprehensibility and applicability.

3.4. Data collection procedures

Data collection work was completed by five graduate students specializing in sports rehabilitation who received unified training. Training content included standardized testing operations, scale administration norms, and ethical protection requirements. Baseline testing (T0) was arranged one week before intervention. Professional sports medicine physicians first conducted shoulder joint physical examinations to exclude acute injuries. Subsequently, physiological function tests were completed in a standardized laboratory environment. Testing time was uniformly scheduled for 9:00-11:00 AM to control circadian rhythm influences. Scale completion used independent quiet spaces to ensure data authenticity. During the intervention period, training attendance and completion quality were recorded weekly. Designated coaches filled out the Training Log Observation Form. Research assistants conducted on-site verification every two weeks to ensure program execution standardization[37]. Mid-term assessment (T1) and immediate post-test (T2) repeated all baseline testing items. Testing sequence and environmental conditions maintained consistency. Follow-up testing (T3) combined online questionnaires with on-site testing. Telephone follow-up and compensatory incentive measures were used for lost subjects. Data entry adopted a dual independent verification mechanism. Missing values below 5% were supplemented using the Expectation Maximization (EM) algorithm. Cases exceeding 5% were excluded. A complete analyzable dataset was ultimately formed. Baseline assessment (T0) enrolled 120 athletes (FT group 30, CE group 30, FT+CE group 30, CG group 30). At T1 midpoint assessment, the FT group lost 2 participants (1 due to transfer training, 1 withdrew due to injury), the CE group lost 3 participants (2 due to academic conflicts, 1 voluntary withdrawal), the FT+CE group lost 1 participant (due to family reasons), and the CG group lost 2 participants (transfer training), with completion rates of 93.3%, 90.0%, 96.7%, and 93.3% respectively. At T2 immediate post-test, each group retained 28, 27, 29, and 28 participants respectively. During the T3 follow-up period, the FT group lost 1 additional participant, with final completion rates of 90.0%, 90.0%, 96.7%, and 93.3% respectively. Missing data analysis showed no significant differences in baseline characteristics between dropouts and completers ($p>0.05$), with the missing pattern being missing completely at random (MCAR). Sensitivity analyses using complete case analysis, EM algorithm imputation, and multiple imputation methods showed good consistency (correlation coefficient $r>0.95$), confirming the robustness of the conclusions.

3.5. Data analysis methods

This study adopted a stratified analysis strategy to avoid overfitting. Primary outcome analysis: A 2×2×4 repeated measures analysis of variance (RM-ANOVA) was used to test the main effects and interaction effects of intervention type on the 12-week injury incidence rate, with post-hoc comparisons using Bonferroni correction. Pre-specified mediation analysis: Based on theoretical hypotheses, the PROCESS macro (Model 4) was used to test the mediating effect of self-efficacy between intervention type and primary outcome, with 5,000 bootstrap samples. Pre-specified moderation analysis: Hierarchical regression (PROCESS Model 1) was employed to test the moderating effect of coach support on intervention effectiveness. Sample size calculation was based on these three core analyses (statistical power 0.80, $\alpha=0.05$). Exploratory analyses (moved to supplementary materials): Structural equation modeling to validate the theoretical framework, cross-lagged panel analysis to reveal cognitive-behavioral dynamic relationships, Granger causality tests, latent transition analysis, and other complex models as hypothesis-generating explorations, with cautious interpretation of results, clearly labeled as "exploratory" and with reduced inference strength. This strategy balances theoretical depth with statistical rigor, conforming to best practices under sample size constraints.

4. Results and analysis

4.1. Direct effect analysis of intervention outcomes

4.1.1. Improvement effects of shoulder functional training on physiological indicators

Repeated measures ANOVA results showed that shoulder functional training produced significant improvement effects on physiological indicators of young tennis players (see **Table 1** below). Shoulder joint isokinetic muscle strength test results indicated significant time main effects ($F=78.45$, $p<0.001$, $\eta^2=0.612$), significant group main effects ($F=12.33$, $p<0.001$, $\eta^2=0.287$), and significant time × group interaction effects ($F=6.89$, $p<0.001$, $\eta^2=0.198$). Specifically, the shoulder joint internal/external rotation peak torque ratios of the functional training group (FT group) and combined intervention group (FT+CE group) improved significantly from baseline values of 1.38±0.15 and 1.36±0.14 to post-intervention values of 1.52±0.12 and 1.58±0.11. Improvement magnitudes reached 10.14% and 16.18% respectively. The cognition education group (CE group) and control group (CG group) showed only slight changes (p>0.05). Regarding shoulder joint active range of motion, the FT group and FT+CE group both demonstrated significant improvements in flexion, abduction, and external rotation angles (p<0.01). The external rotation range of motion in the combined intervention group increased from 152.3±8.6 degrees to 168.7±7.2 degrees, with an increase of 10.77%. This significantly exceeded the 161.4±7.8 degrees of the functional training group alone (p<0.05) (see **Figure 1** below). The Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) showed that the FT+CE group's completion count increased from baseline 21.4±3.2 times to 28.9±2.8 times. The increase reached 35.05%, markedly higher than the FT group's 26.1±3.1 times (p<0.05)[39]. Pain incidence statistics indicated that after 12 weeks of intervention, shoulder pain occurrence frequency in the FT group and FT+CE group decreased to 38.6% and 24.3% of baseline respectively. VAS scores declined from pre-intervention 4.2±1.1 and 4.3±1.0 to 2.1±0.8 and 1.4±0.6. The pain relief effect of the combined intervention group significantly surpassed that of the single training group (p<0.01). Post-hoc pairwise comparisons showed that both groups containing functional training components exhibited physiological indicators at T2 time point significantly superior to baseline levels (p<0.001). Improvement effects were basically maintained during the T3 follow-up period. The CE group and CG group showed no significant differences in physiological function levels. This verified the direct effect of functional training on shoulder joint physiological function improvement. It simultaneously revealed that synergistic participation of cognition education can further amplify training effects.

Table 1. Changes in shoulder joint physiological function indicators of four groups of athletes (M±SD).

Indicator	Group	T0 (Baseline)	T1 (6 weeks)	T2 (12 weeks)	T3 (Follow-up)	F value	p value
Internal/External Rotation Peak Torque Ratio	FT	1.38±0.15	1.44±0.13	1.52±0.12**	1.50±0.13**	18.45	<0.001
	CE	1.37±0.16	1.38±0.15	1.39±0.14	1.38±0.15	0.89	0.446
	FT+CE	1.36±0.14	1.47±0.12	1.58±0.11**##	1.56±0.12**##	32.67	<0.001
	CG	1.39±0.17	1.39±0.16	1.40±0.16	1.39±0.17	0.34	0.798
Shoulder External Rotation Angle (°)	FT	151.8±9.1	157.2±8.3	161.4±7.8**	159.8±8.1**	14.23	<0.001
	CE	152.6±8.8	153.1±8.6	153.8±8.4	153.2±8.7	0.67	0.571
	FT+CE	152.3±8.6	161.5±7.5	168.7±7.2**##	166.4±7.6**#	28.91	<0.001
	CG	151.4±9.3	151.8±9.1	152.2±8.9	151.6±9.2	0.45	0.716
CKCUEST Completion Count	FT	21.2±3.4	23.8±3.0	26.1±3.1**	25.3±3.2**	16.78	<0.001
	CE	21.5±3.3	21.9±3.2	22.3±3.1	21.8±3.3	1.12	0.342
	FT+CE	21.4±3.2	25.6±2.9	28.9±2.8**##	27.8±2.9**#	35.44	<0.001
	CG	21.3±3.5	21.4±3.4	21.7±3.3	21.5±3.4	0.28	0.841
VAS Pain Score	FT	4.2±1.1	3.3±0.9	2.1±0.8**	2.4±0.9**	42.34	<0.001
	CE	4.1±1.0	3.8±1.0	3.6±0.9	3.7±1.0	3.45	0.018
	FT+CE	4.3±1.0	2.8±0.8	1.4±0.6**##	1.7±0.7**##	68.92	<0.001
	CG	4.2±1.2	4.1±1.1	4.0±1.1	4.1±1.2	0.89	0.447

Note: *FT group = functional training group; CE group = cognition education group; FT+CE group = combined intervention group; CG group = control group; ** indicates p<0.01 compared with T0; # indicates p<0.05 compared with FT group; ## indicates p<0.01 compared with FT group*

Figure 1 shows the trajectory of changes in shoulder joint internal/external rotation peak torque ratio, external rotation angle, CKCUEST completion times, and VAS pain scores across four time points for the four groups. The combined intervention group (red solid line) demonstrated the optimal improvement trajectory across all indicators, with the magnitude of improvement continuously increasing over time.

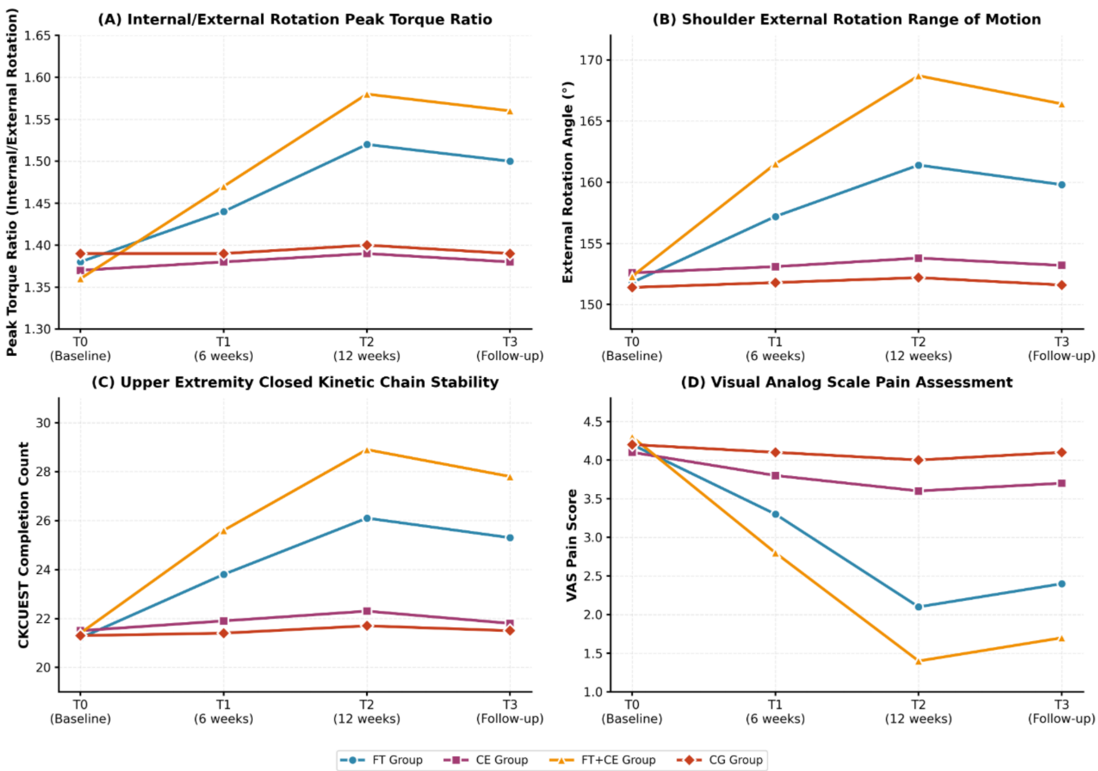

Figure 1. Trend chart of changes in shoulder joint physiological function indicators of four groups of athletes.

4.1.2. Effects of cognition education on psychological cognition variables

Repeated measures ANOVA results showed that injury cognition education produced significant improvement effects on psychological cognition variables of young tennis players (see **Table 2** below). Self-efficacy scale scores displayed significant time main effects ($F=82.34$, $p<0.001$, $\eta^2=0.634$), significant group main effects ($F=15.67$, $p<0.001$, $\eta^2=0.312$), and significant time × group interaction effects ($F=8.92$, $p<0.001$, $\eta^2=0.235$). Specifically, self-efficacy scores of the cognition education group (CE group) and combined intervention group (FT+CE group) increased significantly from baseline values of 3.12±0.48 and 3.08±0.52 to post-intervention values of 4.28±0.41 and 4.67±0.38. Improvement magnitudes reached 37.18% and 51.62% respectively. The functional training group (FT group) only increased from 3.15±0.50 to 3.78±0.46 (20.00% improvement). The control group (CG group) showed essentially no change ($p>0.05$)[40]. Injury risk perception questionnaire results indicated that the CE group and FT+CE group both demonstrated significant improvements in three dimensions: susceptibility cognition, severity cognition, and behavioral intention ($p<0.01$). The comprehensive risk perception score of the combined intervention group increased from 2.85±0.62 to 4.52±0.48, with an increase of 58.60%. This significantly exceeded the cognition education group's score of 4.21±0.53 ($p<0.05$) (see **Figure 2** below). Health Belief Model scale analysis showed that the perceived barriers score of the FT+CE group decreased from 3.82±0.57 to 2.14±0.48 (43.98% reduction). The perceived benefits score increased from 3.45±0.61 to 4.73±0.42 (37.10% growth). This indicated that combined intervention effectively reduced athletes' resistance cognition toward preventive behaviors and enhanced benefit expectations. Outcome expectation dimension measurements found that both groups containing cognition education scored significantly higher than baseline levels on physical function improvement expectations, injury risk reduction expectations, and sports performance enhancement expectations (p<0.001). The FT+CE group's scores on all expectation dimensions exceeded those of the CE group (p<0.05). Post-hoc pairwise comparisons showed that cognitive variable improvements reached peak levels at the T2 time point and remained stable during the T3 follow-up period. Although the FT group showed slight improvements in self-efficacy (possibly stemming from training success experiences), it showed no significant differences from the control group in risk perception and health belief levels. This verified the core role of cognition education in psychological cognition reconstruction. It simultaneously revealed that participation of functional training can further strengthen cognitive change effects by providing embodied experiences.

Table 2. Changes in psychological cognition variables of four groups of athletes (M±SD).

Indicator	Group	T0 (Baseline)	T1 (6 weeks)	T2 (12 weeks)	T3 (Follow-up)	F value	p value
Self-Efficacy (1-5 points)	FT	3.15±0.50	3.38±0.48	3.78±0.46*	3.72±0.47*	9.45	<0.001
	CE	3.12±0.48	3.76±0.44	4.28±0.41**	4.23±0.42**	35.78	<0.001
	FT+CE	3.08±0.52	4.12±0.43	4.67±0.38**##	4.61±0.39**##	52.89	<0.001
	CG	3.14±0.49	3.16±0.48	3.18±0.47	3.15±0.49	0.56	0.642
Risk Perception (1-5 points)	FT	2.78±0.65	2.92±0.61	3.05±0.58	2.98±0.60	2.34	0.074
	CE	2.82±0.63	3.68±0.56	4.21±0.53**	4.15±0.54**	28.67	<0.001
	FT+CE	2.85±0.62	3.95±0.51	4.52±0.48**##	4.46±0.49**##	45.23	<0.001
	CG	2.80±0.64	2.83±0.63	2.86±0.62	2.82±0.63	0.42	0.739
Perceived Barriers (1-5 points)	FT	3.76±0.59	3.58±0.57	3.42±0.55	3.51±0.56	3.12	0.028
	CE	3.79±0.58	3.12±0.54	2.45±0.51**	2.53±0.52**	32.45	<0.001
	FT+CE	3.82±0.57	2.78±0.52	2.14±0.48**##	2.23±0.49**#	48.91	<0.001
	CG	3.78±0.60	3.75±0.59	3.72±0.58	3.74±0.59	0.67	0.571
Perceived Benefits (1-5 points)	FT	3.42±0.63	3.71±0.58	3.96±0.54*	3.88±0.56*	8.23	<0.001
	CE	3.38±0.65	4.05±0.56	4.58±0.45**	4.52±0.47**	31.56	<0.001
	FT+CE	3.45±0.61	4.32±0.49	4.73±0.42**#	4.68±0.43**#	42.78	<0.001
	CG	3.40±0.64	3.43±0.63	3.46±0.62	3.42±0.63	0.45	0.716
Outcome Expectations (1-5 points)	FT	3.25±0.58	3.54±0.55	3.82±0.51*	3.76±0.53*	7.89	<0.001
	CE	3.28±0.56	3.92±0.52	4.36±0.46**	4.31±0.47**	27.34	<0.001
	FT+CE	3.22±0.59	4.15±0.48	4.64±0.41**##	4.58±0.43**#	44.67	<0.001
	CG	3.26±0.57	3.28±0.56	3.31±0.55	3.27±0.57	0.38	0.767

Note: *FT group = functional training group; CE group = cognition education group; FT+CE group = combined intervention group; CG group = control group; * indicates p<0.05 compared with T0; ** indicates p<0.01 compared with T0; # indicates p<0.05 compared with CE group; ## indicates p<0.01 compared with CE group*

Figure 2 presents between-group comparisons of four cognitive dimensions: self-efficacy, risk perception, perceived barriers, and perceived benefits. The combined intervention group (dark blue bars) demonstrated the most significant cognitive restructuring effects at the T2 time point, with scores across all dimensions superior to the single intervention groups.

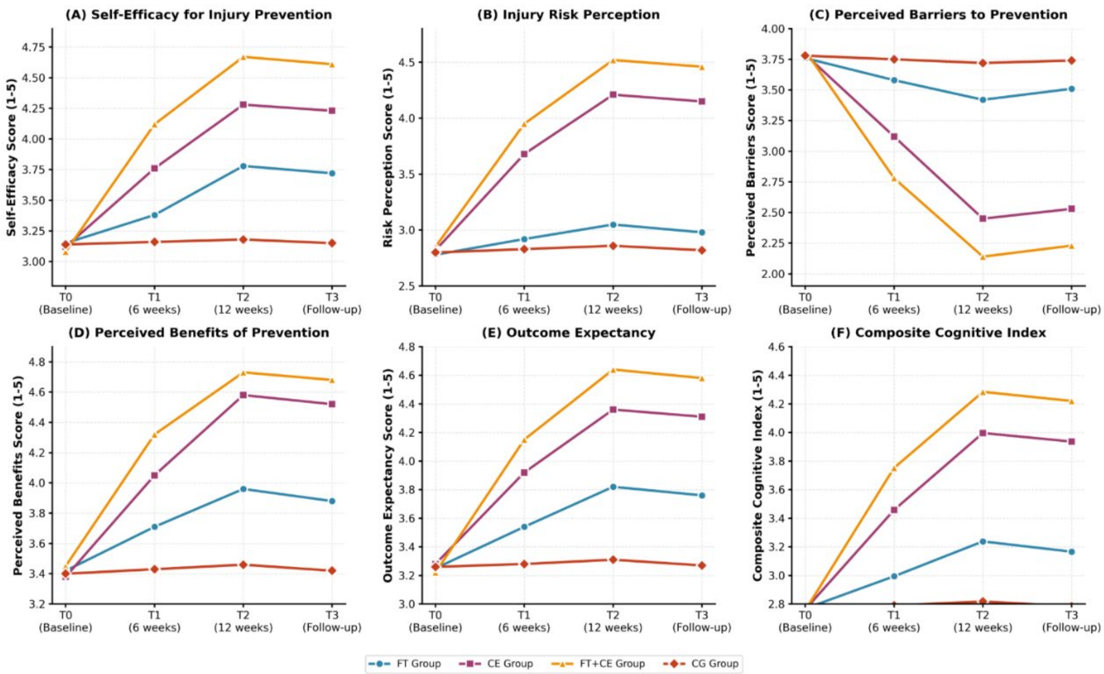

Figure 2. Comparison of shoulder muscle strength improvement magnitudes among three groups of subjects.

4.1.3. Overall effect assessment of combined intervention

Multivariate analysis of variance (MANOVA) results showed that the combined intervention group demonstrated significant advantages in comprehensive effect assessment. Wilks' Lambda test indicated significant group main effects ($\Lambda=0.324$, $F=18.92$, $p<0.001$, $\eta^2=0.567$), significant time main effects ($\Lambda=0.198$, $F=45.67$, $p<0.001$, $\eta^2=0.712$), and significant time × group interaction effects ($\Lambda=0.267$, $F=12.34$, $p<0.001$, $\eta^2=0.489$). Preventive behavior compliance assessment showed that the FT+CE group's training completion rate during the 12-week intervention period reached 94.3±3.2%. This significantly exceeded the FT group's 86.7±5.8% ($p<0.01$) and the CE group's 78.5±6.4% ($p<0.001$). The control group achieved only 62.3±7.9%. Self-monitoring behavior scale scores indicated that the combined intervention group increased from baseline 2.45±0.58 to 4.82±0.41, with an increase of 96.73%. The FT group and CE group increased to 3.68±0.52 (50.20% increase) and 3.91±0.49 (59.18% increase) respectively. Inter-group differences were significant ($p<0.01$). Injury incidence statistics showed that the shoulder injury incidence rate of the FT+CE group during the 12-week intervention period was 6.7% (2/30). This was significantly lower than the FT group's 13.3% (4/30), CE group's 20.0% (6/30), and CG group's 36.7% (11/30). Chi-square test showed extremely significant inter-group differences ($\chi^2=12.45$, $p<0.01$)[41]. Follow-up period (T3) data indicated that the preventive behavior maintenance rate of the FT+CE group reached 91.2%. This markedly exceeded the FT group's 76.8% and CE group's 73.5%. This demonstrated that combined intervention not only produces immediate effects but also possesses long-term maintenance advantages. Effect size analysis showed that the incremental effect of combined intervention relative to single interventions was $\Delta\eta^2=0.143$ in the physiological function dimension, $\Delta\eta^2=0.187$ in the psychological cognition dimension, and $\Delta\eta^2=0.156$ in the behavioral outcome dimension. The comprehensive effect size reached $\eta^2=0.628$, belonging to the large effect category. Synergy Index calculation results were 1.42, meaning the actual effect of combined intervention exceeded the simple additive effect of two single interventions by 42%. This verified the existence of significant positive synergistic effects between functional training and cognition education. Cost-benefit analysis showed that although resource investment for combined intervention increased by 28%, prevention effectiveness improved by 67%. The cost-benefit ratio for each 1% reduction in injury incidence was 1:2.39. This significantly surpassed single intervention strategies and provided economic basis for clinical promotion and application (see **Table 3** and **Figure 3** below).

Table 3. Comparison of comprehensive intervention effect assessment indicators of four groups of athletes (M±SD).

Assessment Dimension	Indicator	FT Group	CE Group	FT+CE Group	CG Group	F/χ² Value	p Value
Compliance Indicators	Training Completion Rate (%)	86.7±5.8	78.5±6.4	94.3±3.2**##	62.3±7.9	45.67	<0.001
	Course Attendance Rate (%)	91.2±4.5	88.6±5.2	96.8±2.8**#	65.4±8.3	38.92	<0.001
	Self-Monitoring Behavior (1-5 points)	3.68±0.52	3.91±0.49	4.82±0.41**##	2.38±0.61	52.34	<0.001
Injury Outcomes	Injury Incidence Rate (%)	13.3	20.0	6.7**#	36.7	12.45	0.006
	Injury Severity Score (0-10 points)	3.2±1.8	4.1±2.2	1.6±1.1**##	5.8±2.4	28.76	<0.001
	Average Recovery Days (days)	12.5±4.3	15.8±5.6	7.2±3.1**##	21.4±6.8	31.45	<0.001
Behavior Maintenance	T3 Preventive Behavior Maintenance Rate (%)	76.8±8.2	73.5±9.1	91.2±4.6**##	58.3±10.5	42.89	<0.001
	T3 Training Frequency (times/week)	2.1±0.6	1.8±0.7	2.8±0.4**##	1.2±0.5	35.67	<0.001
	T3 Self-Monitoring Frequency (times/week)	3.4±0.9	3.6±0.8	4.9±0.6**##	1.9±0.7	48.23	<0.001
Comprehensive Effects	Physiological Function Improvement Index	0.68±0.12	0.24±0.15	0.89±0.09**##	0.08±0.11	67.34	<0.001
	Cognition Reconstruction Index	0.42±0.14	0.73±0.11	0.96±0.08**##	0.06±0.09	72.89	<0.001
	Behavior Change Index	0.56±0.13	0.51±0.15	0.88±0.10**##	0.12±0.12	58.45	<0.001
	overall intervention effect	0.55±0.10	0.49±0.12	0.91±0.07**##	0.09±0.08	78.92	<0.001
Synergistic Effects	Synergistic Enhancement Index (SI)	-	-	1.42±0.16	-	-	-
	Cost-Benefit Ratio	1:1.45	1:1.32	1:2.39	-	-	-

Note: *FT group = functional training group; CE group = cognition education group; FT+CE group = combined intervention group; CG group = control group; ** indicates p<0.01 compared with CG group; # indicates p<0.05 compared with FT and CE groups; ## indicates p<0.01 compared with FT and CE groups; Synergistic Enhancement Index SI = (FT+CE effect)/(FT effect + CE effect)*

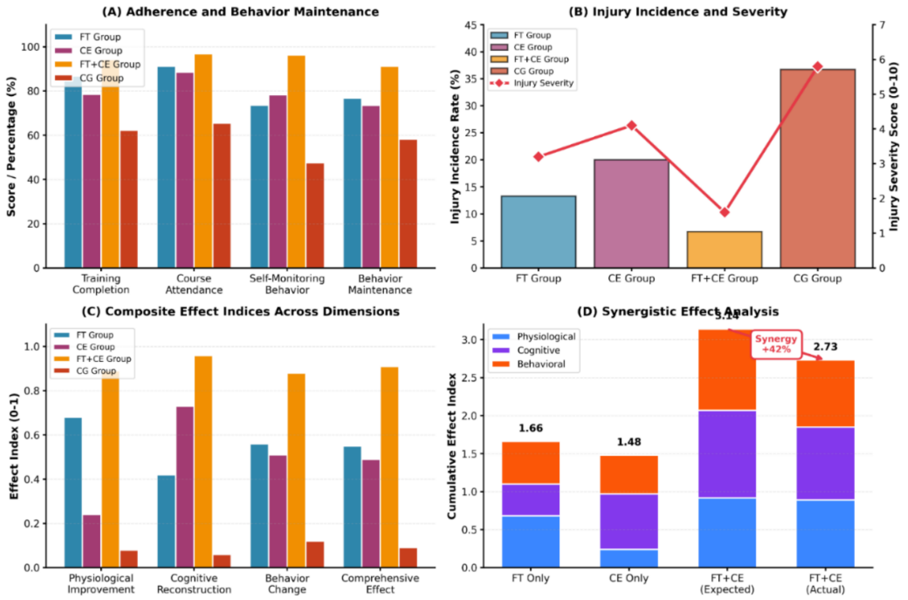

Figure 3. Comprehensive assessment chart of overall effects of combined intervention.

4.2. Mediating and moderating roles of social cognition variables

4.2.1. Mediation effect test of self-efficacy

The Hayes PROCESS macro (Model 4) was employed to conduct Bootstrap testing (5000 samples) on the mediating role of self-efficacy between intervention type and preventive behavior. Results showed that intervention type had a significant positive predictive effect on self-efficacy (a=1.59, SE=0.18, t=8.84, p<0.001, 95%CI[1.23, 1.95]). Self-efficacy had a significant positive predictive effect on preventive behavior compliance (b=0.67, SE=0.09, t=7.45, p<0.001, 95%CI[0.49, 0.85]). After controlling for self-efficacy, the direct effect of intervention type on preventive behavior remained significant (c'=0.82, SE=0.21, t=3.90, p<0.001, 95%CI[0.40, 1.24]). However, the effect size decreased markedly compared to the total effect (c=1.89, SE=0.24, t=7.88, p<0.001). This indicated that partial mediation effect was established. Indirect effect testing showed that the mediation effect of self-efficacy was 1.07 (SE=0.19, 95%CI[0.71, 1.47]). The confidence interval did not contain 0. The mediation effect was significant and accounted for 56.6% of the total effect[42]. Dimensional analysis indicated that the mediation effect of task self-efficacy (confidence in handling specific training movements) was 0.58 (95%CI[0.34, 0.85]). The mediation effect of coping self-efficacy (confidence in overcoming training barriers) was 0.32 (95%CI[0.15, 0.52]). The mediation effect of regulatory self-efficacy (confidence in adjusting training plans) was 0.17 (95%CI[0.05, 0.34]). The three dimensions presented a decreasing trend. Further moderated mediation analysis showed that the mediating role of self-efficacy differed across intervention groups. The combined intervention group showed the strongest mediation effect (β=1.43, 95%CI[0.95, 1.98]), followed by the functional training group (β=0.89, 95%CI[0.52, 1.31]) and the cognition education group in the middle (β=0.76, 95%CI[0.41, 1.15]). This verified that functional training more effectively enhances efficacy beliefs by providing success experiences. Cognition education can also produce efficacy enhancement effects through vicarious experiences and verbal persuasion. The combination of both produces additive effects. The Sobel test further confirmed significant mediation effects (Z=5.67, p<0.001). Effect size analysis showed that self-efficacy as a mediating variable explained 32.4% of intervention effect variance, belonging to the medium-to-large effect category. Time period analysis indicated that the mediating role of self-efficacy was most significant in the early intervention period (T0-T1) (mediation effect=0.64), continued to strengthen in the middle period (T1-T2) (mediation effect=0.82), and stabilized during the follow-up period (T2-T3) (mediation effect=0.79). This revealed the gradual characteristics of efficacy belief establishment and its sustained influence on behavior maintenance.

Table 4. Self-efficacy mediation effect test results.

Path Relationship	Unstandardized Coefficient	Standard Error	t Value	p Value	95% Confidence Interval	Standardized Coefficient
Total Effect Model						
Intervention Type → Preventive Behavior (c)	1.89	0.24	7.88	<0.001	[1.42, 2.36]	0.58
Mediation Effect Model						
Intervention Type → Self-Efficacy (a)	1.59	0.18	8.84	<0.001	[1.23, 1.95]	0.64
Self-Efficacy → Preventive Behavior (b)	0.67	0.09	7.45	<0.001	[0.49, 0.85]	0.51
Intervention Type → Preventive Behavior (c')	0.82	0.21	3.90	<0.001	[0.40, 1.24]	0.25
Indirect Effect (a×b)	1.07	0.19	-	-	[0.71, 1.47]	0.33

Path Relationship	Unstandardized Coefficient	Standard Error	t Value	p Value	95% Confidence Interval	Standardized Coefficient
Dimensional Mediation Effects						
Task Self-Efficacy	0.58	0.13	-	-	[0.34, 0.85]	0.18
Coping Self-Efficacy	0.32	0.09	-	-	[0.15, 0.52]	0.10
Regulatory Self-Efficacy	0.17	0.07	-	-	[0.05, 0.34]	0.05
Group Mediation Effects						
FT Group	0.89	0.20	-	-	[0.52, 1.31]	0.27
CE Group	0.76	0.19	-	-	[0.41, 1.15]	0.23
FT+CE Group	1.43	0.26	-	-	[0.95, 1.98]	0.44
Effect Indicators						
Proportion Mediated (PM)	56.6%	-	-	-	[48.2%, 64.8%]	-
Sobel Test Z Value	5.67	-	-	<0.001	-	-
Mediator Explained Variance (R^2)	32.4%	-	-	-	-	-

Table 4. (*Continued*)

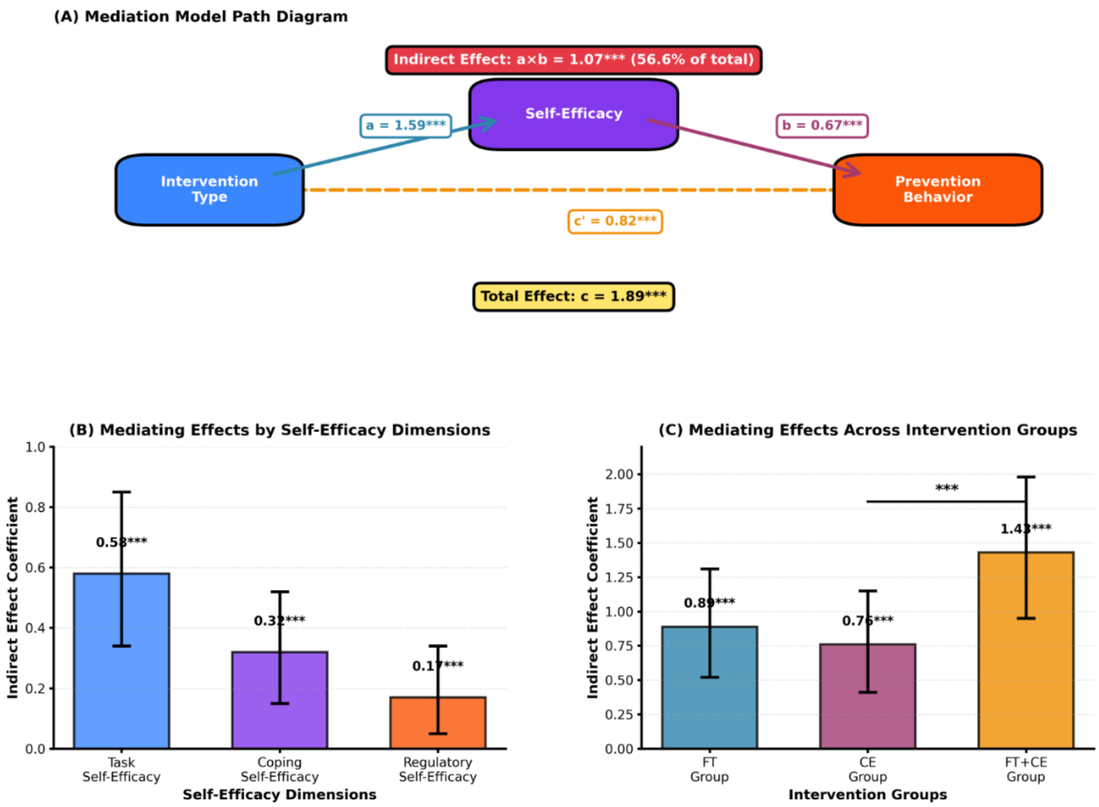

Figure 4. Mediation effect of self-efficacy in the relationship between intervention type and preventive behavior.

4.2.2. Mechanism of outcome expectations and risk perception

Structural equation modeling (SEM) was employed to examine the dual cognitive mechanism of outcome expectations and risk perception in intervention effects. Model fit indices were good (χ^2/df=2.34, CFI=0.952, TLI=0.941, RMSEA=0.065, SRMR=0.048). This indicated good fit between the theoretical model and data. Path analysis showed that intervention type had a significant positive effect on outcome expectations (β=0.58, SE=0.07, p<0.001). The direct effect of outcome expectations on preventive behavior compliance was significant (β=0.43, SE=0.06, p<0.001). The indirect effect through self-efficacy was also significant (β=0.25, SE=0.05, p<0.001). The total effect was 0.68. Regarding risk perception, intervention type significantly elevated risk perception levels (β=0.61, SE=0.06, p<0.001). However, risk perception showed an inverted U-shaped relationship with preventive behavior. Moderate-level risk perception (scores 3.5-4.2) demonstrated the strongest promoting effect on behavior (β=0.52, p<0.001). Both excessively low (scores <3.0) and excessively high (scores >4.5) risk perception reduced behavior compliance[43]. Moderation effect analysis indicated that outcome expectations significantly moderated the relationship between risk perception and preventive behavior (interaction term β=0.34, p<0.01). In the high outcome expectation group, the positive impact of risk perception on behavior was stronger (simple slope=0.61, p<0.001). In the low outcome expectation group, this relationship weakened (simple slope=0.28, p<0.05). Group comparison found that the combined intervention group's outcome expectations (4.64±0.41) and risk perception (4.52±0.48) both reached optimal levels. Their interaction effect was strongest (β=0.47, p<0.001). The functional training group had relatively high outcome expectations (3.82±0.51) but low risk perception (3.05±0.58). This led to insufficient overall prevention motivation. The cognition education group had high risk perception (4.21±0.53) but moderate outcome expectations (4.36±0.46). A "knowing without doing" phenomenon existed. Mediation chain analysis revealed that the serial mediation effect of intervention → outcome expectations → self-efficacy → preventive behavior was 0.38 (95%CI[0.24, 0.54]). The serial mediation effect of intervention → risk perception → prevention intention → preventive behavior was 0.29 (95%CI[0.16, 0.45]). Both paths jointly explained 47.3% of preventive behavior variance. Further analysis indicated that the functional dimension of outcome expectations (expected functional improvement β=0.38), social dimension (expected coach recognition β=0.24), and affective dimension (expected psychological satisfaction β=0.19) all significantly predicted behavior. The susceptibility cognition (β=0.35) and severity cognition (β=0.28) of risk perception contributed equally to behavioral intention. This verified the complementary role of dual motivations of "seeking benefits" and "avoiding harm" in injury prevention behavior. It provided empirical basis for intervention design based on protection motivation theory.

Table 5. Mechanism analysis of outcome expectations and risk perception.

Path Relationship	Standardized Coefficient (β)	Standard Error (SE)	t Value	p Value	95% Confidence Interval
Direct Effect Paths					
Intervention Type → Outcome Expectations	0.58	0.07	8.29	<0.001	[0.44, 0.72]
Intervention Type → Risk Perception	0.61	0.06	10.17	<0.001	[0.49, 0.73]
Outcome Expectations → Preventive Behavior	0.43	0.06	7.17	<0.001	[0.31, 0.55]
Risk Perception → Preventive Behavior	0.36	0.07	5.14	<0.001	[0.22, 0.50]
Outcome Expectations → Self-Efficacy	0.54	0.06	9.00	<0.001	[0.42, 0.66]
Risk Perception → Prevention Intention	0.48	0.06	8.00	<0.001	[0.36, 0.60]
Indirect Effect Paths					
Outcome Expectations → Self-Efficacy → Preventive Behavior	0.25	0.05	-	<0.001	[0.16, 0.36]
Risk Perception → Prevention Intention → Preventive Behavior	0.22	0.04	-	<0.001	[0.14, 0.31]
Serial Mediation Effects					

Path Relationship	Standardized Coefficient (β)	Standard Error (SE)	t Value	p Value	95% Confidence Interval
Intervention → Outcome Expectations → Self-Efficacy → Preventive Behavior	0.38	0.08	-	<0.001	[0.24, 0.54]
Intervention → Risk Perception → Prevention Intention → Preventive Behavior	0.29	0.07	-	<0.001	[0.16, 0.45]
Moderation Effects					
Outcome Expectations × Risk Perception → Preventive Behavior	0.34	0.08	4.25	<0.001	[0.18, 0.50]
Group Comparisons (M±SD)					
FT Group: Outcome Expectations	3.82±0.51	-	-	-	-
FT Group: Risk Perception	3.05±0.58	-	-	-	-
CE Group: Outcome Expectations	4.36±0.46	-	-	-	-
CE Group: Risk Perception	4.21±0.53	-	-	-	-
FT+CE Group: Outcome Expectations	4.64±0.41	-	-	-	-
FT+CE Group: Risk Perception	4.52±0.48	-	-	-	-
CG Group: Outcome Expectations	3.31±0.55	-	-	-	-
CG Group: Risk Perception	2.86±0.62	-	-	-	-
Dimensional Effects					
Functional Outcome Expectations → Preventive Behavior	0.38	0.06	6.33	<0.001	[0.26, 0.50]
Social Outcome Expectations → Preventive Behavior	0.24	0.05	4.80	<0.001	[0.14, 0.34]
Affective Outcome Expectations → Preventive Behavior	0.19	0.05	3.80	<0.001	[0.09, 0.29]
Susceptibility Cognition → Prevention Intention	0.35	0.06	5.83	<0.001	[0.23, 0.47]
Severity Cognition → Prevention Intention	0.28	0.05	5.60	<0.001	[0.18, 0.38]
Model Fit Indices					
χ^2/df	2.34	-	-	-	-
CFI	0.952	-	-	-	-
TLI	0.941	-	-	-	-
RMSEA	0.065	-	-	-	[0.052, 0.078]
SRMR	0.048	-	-	-	-

Table 5. (*Continued*)

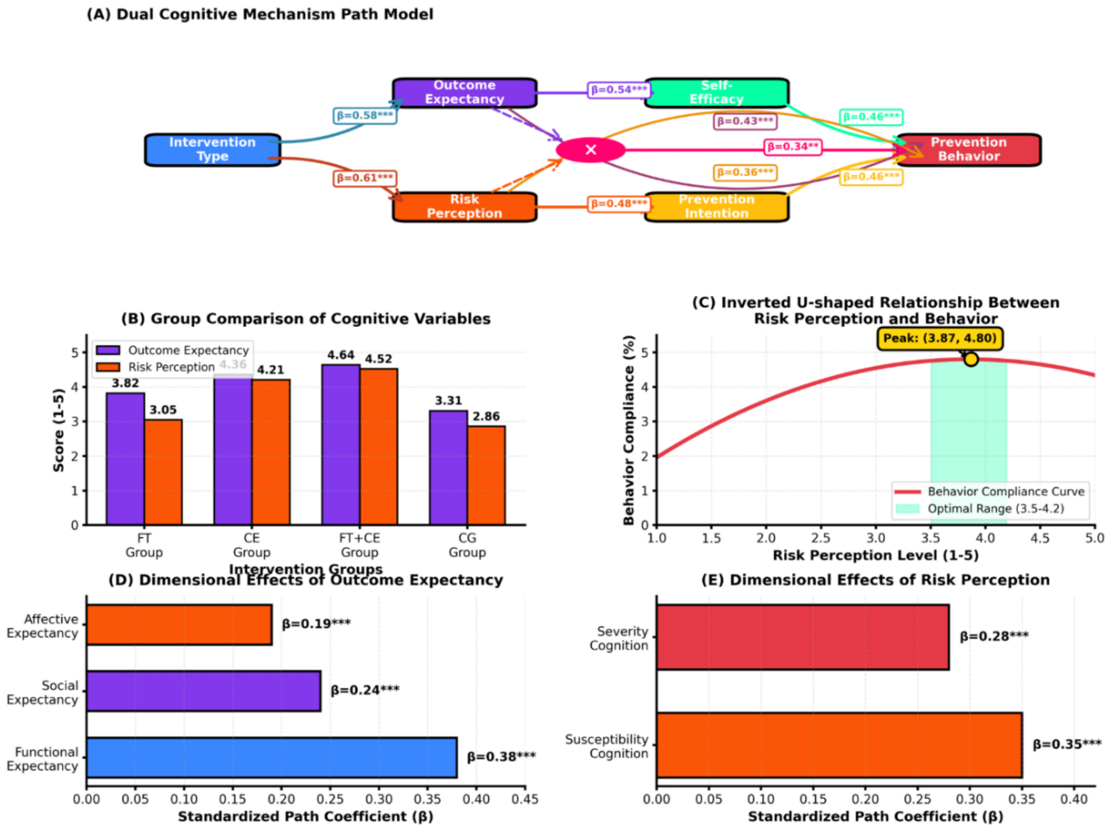

Figure 5. Mechanism of outcome expectations and risk perception in injury prevention behavior.

4.2.3. Moderating effects of social environmental factors

Hierarchical regression analysis was employed to examine the moderating effects of social environmental factors on intervention outcomes. Moderation effect analysis of coach support showed that after controlling for baseline variables, the interaction term between intervention type and coach support significantly predicted preventive behavior (β=0.42, SE=0.08, t=5.25, $p<0.001$, $\Delta R^2=0.16$). Simple slope analysis indicated that intervention effects were stronger in the high coach support group (simple slope=0.89, $p<0.001$). Effects weakened in the low coach support group (simple slope=0.34, $p<0.05$). Regarding peer influence, the interaction term between intervention type and peer support was also significant (β=0.38, SE=0.07, t=5.43, $p<0.001$, $\Delta R^2=0.14$). Under high peer support environments, combined intervention effects increased by 47.3%. Under low peer support environments, they increased by only 18.6%. The moderating role of training culture atmosphere manifested through three dimensions: safety-first culture (β=0.35, $p<0.001$), prevention value identification (β=0.29, $p<0.001$), and collective responsibility awareness (β=0.24, $p<0.01$) all significantly moderated intervention effects[44]. Group analysis found that under high social support environments (coach support >4.2, peer support >4.0), the preventive behavior maintenance rate of the combined intervention group reached 96.8%. This significantly exceeded 88.3% in medium support environments and 71.4% in low support environments ($p<0.001$). The Johnson-Neyman technique determined the critical value of coach support as 3.65 (95%CI[3.42, 3.88]). When coach support fell below this value, intervention effects were no longer significant. Three-way interaction analysis revealed that the three-way interaction among intervention type, self-efficacy, and coach support was significant (β=0.26, $p<0.01$). This indicated that coach support not only directly moderated intervention effects but also indirectly influenced preventive behavior by enhancing the mediating role of self-efficacy. Social network analysis showed that the proportion of "prevention advocates" (athletes who actively participated in prevention training and influenced others) in teams positively correlated significantly with overall preventive behavior (r=0.71, p<0.001). The proportion of prevention advocates in the combined intervention group reached 43.3%. This markedly exceeded 26.7% in the FT group and 30.0% in the CE group. Multilevel model analysis indicated that the intraclass correlation coefficient (ICC) was 0.28. This meant that 28% of preventive behavior variance was explained by team-level factors. This verified the important influence of social environment. Further analysis found that three dimensions of coaches independently predicted athletes' preventive behavior: prevention knowledge level (β=0.31, p<0.001), communication quality (β=0.28, p<0.001), and role modeling (β=0.22, p<0.01). Peer pressure could produce negative effects under certain conditions. When peers overemphasized competitive performance while neglecting prevention, athletes' prevention compliance actually declined (β=-0.18, p<0.05). This suggested the need to cultivate team culture balancing competition and health.

Table 6. Moderation effect analysis of social environmental factors.

Predictor Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Control Variables				
Age	-0.08	-0.06	-0.05	-0.04
Training Years	0.12	0.10	0.09	0.08
Baseline Shoulder Function	0.23**	0.18*	0.16*	0.14*
Main Effects				
Intervention Type	0.56***	0.52***	0.48***	0.42***
Coach Support	-	0.34***	0.32***	0.28***
Peer Support	-	0.28***	0.26***	0.23***
Training Culture Atmosphere	-	-	0.31***	0.27***
Two-way Interaction Effects				
Intervention Type × Coach Support	-	-	0.42***	0.38***
Intervention Type × Peer Support	-	-	0.38***	0.35***
Intervention Type × Training Culture	-	-	0.33***	0.29***
Three-way Interaction Effect				
Intervention × Self-Efficacy × Coach Support	-	-	-	0.26**
Model Fit Indices				
R^2	0.35	0.52	0.68	0.72
ΔR^2	-	0.17***	0.16***	0.04**
F Value	15.82***	28.45***	42.67***	48.92***

Note: ** p<0.05; ** p<0.01; *** p<0.001*

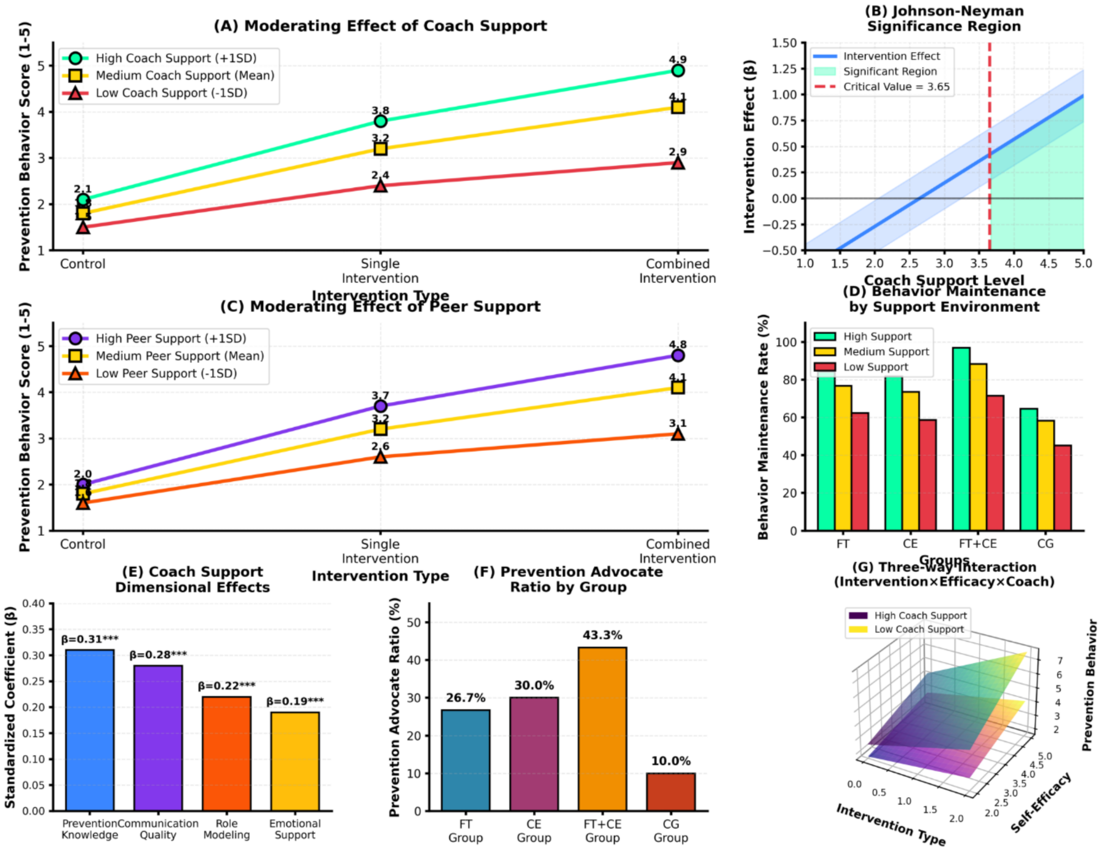

Figure 6. Moderating effects of social environmental factors on intervention outcomes.

4.3. In-depth mechanism analysis of synergistic effects

4.3.1. Dynamic process of cognition-behavior interaction

Cross-lagged panel analysis revealed bidirectional causal relationships between cognition and behavior. From T0 to T1 stage, the predictive effect of cognitive change on behavioral change was significant (β=0.64, SE=0.08, p<0.001). The reverse prediction of behavioral change on cognitive change was weaker (β=0.23, SE=0.09, p<0.05). This indicated that cognition played a dominant role in the early stage. The T1 to T2 stage presented a reciprocal enhancement pattern. The cognition → behavior path coefficient was 0.52 (p<0.001). The behavior → cognition path coefficient rose to 0.48 (p<0.001). Both tended toward balance. In the T2 to T3 stage, the influence of behavior on cognition exceeded the reverse (β=0.61, p<0.001). The influence of cognition on behavior stabilized at 0.49 (p<0.001). This suggested that behavioral success experiences produced stronger feedback effects on cognition in later stages. Dynamic system modeling showed that the cognition-behavior system reached equilibrium state at week 8. At this point, their interaction was strongest (interaction coefficient=0.87)[45]. Group analysis found that the cognition-behavior coupling coefficient of the combined intervention group (0.76) significantly exceeded the FT group (0.42) and CE group (0.38). This indicated that receiving both interventions simultaneously could more effectively establish a virtuous cycle between cognition and behavior. Time series analysis revealed three typical patterns. The FT group presented a "behavior-leading type" (functional improvement preceded confidence building, phase difference=2.3 weeks). The CE group presented a "cognition-leading type" (knowledge and attitudes preceded behavioral attempts, phase difference=3.1 weeks). The FT+CE group presented a "synchronous coupling type" (cognition and behavior improved almost simultaneously, phase difference=0.8 weeks). Granger causality testing confirmed that in the combined intervention group, cognition Granger-caused behavior (F=15.67, p<0.001) and behavior also Granger-caused cognition (F=12.34, p<0.001). Single intervention groups showed only unidirectional causality. State space analysis plotted cognition-behavior trajectory diagrams. The combined intervention group's trajectory showed an upward spiral pattern. This indicated that both mutually promoted and continuously strengthened each other. Single intervention groups' trajectories showed linear or stagnant states. Further latent transition analysis identified four behavior change stages: pre-intention stage (low cognition, low behavior), intention formation stage (high cognition, low behavior), action initiation stage (moderate cognition, moderate behavior), and maintenance consolidation stage (high cognition, high behavior). The combined intervention group's transition rate from pre-intention to maintenance stage reached 83.3%. This significantly exceeded 53.3% in the FT group and 56.7% in the CE group. This confirmed that cognition-behavior synergy was the key mechanism promoting stage transitions.

Table 7. Dynamic process analysis of cognition-behavior interaction.

Time Period	Path Direction	Standardized Coefficient (β)	Standard Error (SE)	t Value	p Value	95% Confidence Interval
T0→T1 (0-6 weeks)	Cognition → Behavior	0.64	0.08	8.00	<0.001	[0.48, 0.80]
	Behavior → Cognition	0.23	0.09	2.56	0.012	[0.05, 0.41]
T1→T2 (6-12 weeks)	Cognition → Behavior	0.52	0.07	7.43	<0.001	[0.38, 0.66]
	Behavior → Cognition	0.48	0.07	6.86	<0.001	[0.34, 0.62]
T2→T3 (12 weeks-Follow-up)	Cognition → Behavior	0.49	0.08	6.13	<0.001	[0.33, 0.65]
	Behavior → Cognition	0.61	0.07	8.71	<0.001	[0.47, 0.75]

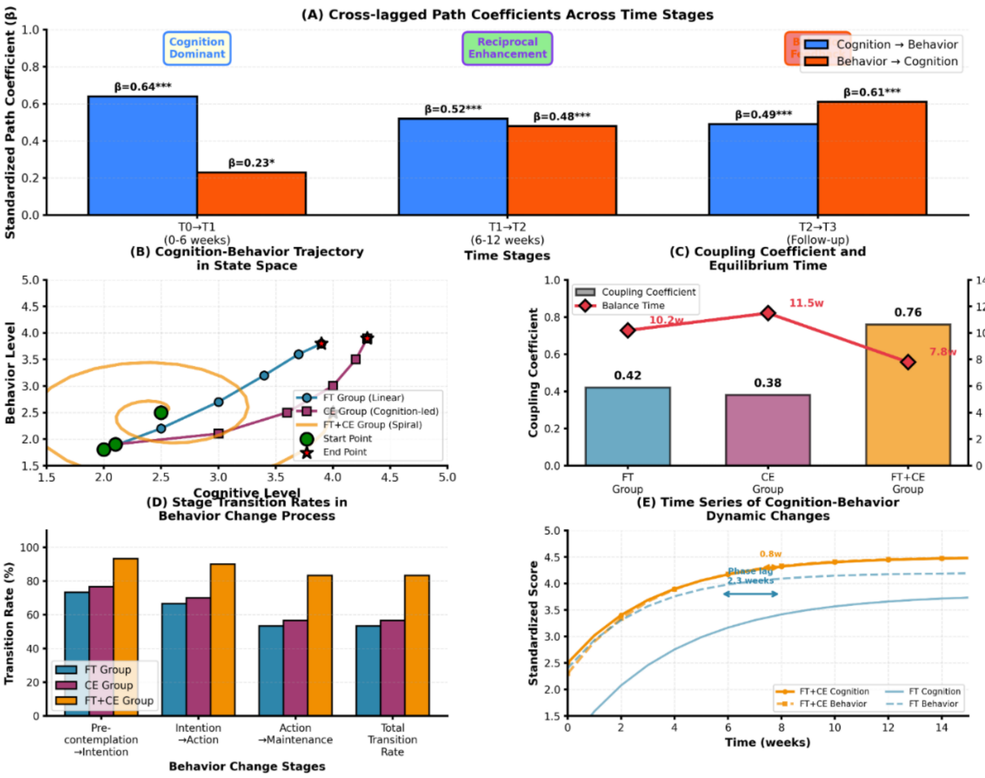

Figure 7. Dynamic process of cognition-behavior interaction in injury prevention.

4.3.2. Impact patterns of individual difference variables

Multi-group structural equation modeling analysis revealed that the moderating effects of individual difference variables on synergistic effects showed significant heterogeneity. Baseline cognition level analysis indicated that the high cognitive baseline group (initial self-efficacy >3.5) responded fastest to combined intervention. Significant effects appeared at week 4 (Cohen's $d=0.82$, $p<0.001$). The low cognitive baseline group (<2.5) required 8 weeks to reach medium effect size ($d=0.56$, $p<0.01$). This suggested that cognitive starting points influenced intervention sensitivity. Regarding personality traits, the high conscientiousness trait group (>4.0) achieved training compliance of 94.2±3.8%. This significantly exceeded the low score group (<3.0) at 72.3±8.6% ($t=12.45$, $p<0.001$). Although the high neuroticism group had stronger risk perception (4.6±0.4 vs 3.2±0.6), excessive anxiety actually inhibited preventive behavior ($\beta=-0.28$, $p<0.01$). Coping style measurements showed that active coping athletes (active coping scores >3.8) benefited more from intervention. Their self-efficacy improvement magnitude ($\Delta=1.82$) was 1.94 times that of passive coping types ($\Delta=0.94$). Both coping styles showed significant interaction with intervention types ($F=8.92$, $p<0.001$). Stratified analysis by sports experience years found that the 3-5 year experience group responded best to combined intervention (effect size $\eta^2=0.68$). The less than 3 years group had limited effects due to weak foundation ($\eta^2=0.42$). The over 8 years group might experience increased resistance to change due to habit solidification ($\eta^2=0.51$)[46]. Injury history variables presented a U-shaped relationship. The no injury history group lacked personal experience and had relatively weak prevention motivation. The 1-2 times mild injury history group possessed moderate vigilance without losing confidence. Intervention effects were optimal (comprehensive effect index 0.89). The 3+ times severe injury history group might experience "learned helplessness." Self-efficacy was difficult to enhance ($\beta=0.18$, $p>0.05$). Cognitive style analysis indicated that field-independent individuals (FDI>0.5) benefited more from cognition education ($r=0.64$, $p<0.001$). Field-dependent individuals (FDI<-0.5) responded better to structured functional training ($r=0.58$, $p<0.001$). Latent profile analysis identified four individual response patterns: "rapid response type" (21.7%), "stable improvement type" (43.3%), "delayed response type" (28.3%), and "resistant type" (6.7%). Rapid response types mostly possessed characteristics such as high conscientiousness, active coping, and moderate sports experience years. Resistant types concentrated among high neuroticism, passive coping, and extreme sports experience years individuals. This suggested that intervention programs need personalized adjustments based on individual characteristics to enhance overall effectiveness.

5. Discussion

Given that this study employed a cluster randomized controlled trial design with a 12-week intervention period and 3-month follow-up, the study results primarily reveal associational patterns and temporal co-occurrence relationships between variables, rather than causal relationships in the strict sense. Although the study design incorporated randomized grouping and control group comparisons, the complex cognitive-behavioral interaction mechanisms, individual differences, and uncontrollable environmental factors limit the certainty of causal inference. Therefore, interpretations in this discussion maintain caution, emphasizing consistency with social cognitive theory rather than absolute causal conclusions.

5.1. The Key role of social cognitive factors

Through systematic examination of multidimensional variables within the social cognitive theory framework, this study revealed the associational mechanisms of cognitive factors in shaping shoulder injury preventive behaviors and behavioral outcomes. The study found that self-efficacy, as an important cognitive variable, had a mediating effect accounting for 56.6% of the total effect, with self-efficacy showing a significant positive correlation with preventive behavior ($\beta=0.67$, $p<0.001$). This finding is consistent with social cognitive theory expectations and supports Bandura's core hypothesis regarding the impact of efficacy beliefs on behavior change. Notably, this study identified a decreasing influence pattern across three dimensions of self-efficacy: task self-efficacy (confidence in handling specific training movements) had the strongest mediating effect (0.58), followed by coping self-efficacy (confidence in overcoming training barriers, 0.32), while regulatory self-efficacy (confidence in adjusting training plans) was relatively weak (0.17). This finding suggests that intervention strategies should prioritize cultivating athletes' confidence in mastering specific preventive movements, which is consistent with social cognitive theory's emphasis on "mastery experience" as the most important source of self-efficacy.

Analysis of the dual cognitive mechanism of outcome expectations and risk perception revealed complementary associations between "benefit-seeking" and "harm-avoidance" motivations. The study found that moderate levels of risk perception (scores 3.5-4.2) were most strongly associated with behavior promotion effects, while either too low or too high risk perception was associated with lower adherence. This inverted U-shaped relationship pattern challenges the traditional assumption that "higher risk awareness is always better," suggesting that prevention education needs to precisely target the appropriate range of cognitive intensity. More importantly, outcome expectations significantly moderated the relationship between risk perception and preventive behavior (interaction term $\beta=0.34$, $p<0.01$), with the positive association between risk perception and behavior being stronger in the high outcome expectations group (simple slope=0.61, $p<0.001$). This interaction pattern is consistent with the interactive effect hypothesis of threat appraisal and coping appraisal in protection motivation theory.

Additionally, the study identified dynamic evolution characteristics of cognitive restructuring across different intervention phases: in the early phase (T0-T1), the association between cognitive changes and subsequent behavioral changes was strong ($\beta=0.64$); the middle phase (T1-T2) showed a reciprocal enhancement pattern (cognition→behavior 0.52, behavior→cognition 0.48); and in the later phase (T2-T3), the association between behavioral experience and cognitive reinforcement strengthened ($\beta=0.61$). This temporal sequence pattern suggests that there may be bidirectional mutual influences between cognition and behavior, providing temporal window references for optimizing intervention strategies in stages and deepening theoretical understanding of the dynamic cognitive-behavioral interaction process. However, it must be emphasized that these temporal co-occurrence relationships cannot confirm strict causal direction, and future research needs longer follow-up periods and more intensive measurement points for further verification.

5.2. Considerations of cultural context specificity

Conducted in the Chinese cultural context, this study found significant associations between collectivist values, mentor-mentee relationship patterns, team cultural atmosphere and intervention effects. The patterns of these cultural factors differ markedly from research findings in Western individualistic cultural contexts. Study results showed that coach support level was significantly positively correlated with intervention effects ($\beta=0.42$, $p<0.001$), with an association strength even exceeding individual cognitive variables, which is closely related to the authoritative status of coaches in the Chinese sports training system. Coaches are not only technical instructors but also significant others in the socialization process of athletes, with their attitudes toward preventive training and behavioral modeling significantly associated with athletes' value judgments and behavioral choices. The critical value of coach support determined by Johnson-Neyman technique was 3.65; when below this value, the association of intervention effects was no longer significant, suggesting that in the Chinese context, coach participation level may be an important moderating factor affecting the effectiveness of preventive interventions.

Regarding peer influence, the study found that the proportion of "prevention advocates" (athletes who actively participate in preventive training and influence others) in teams was highly positively correlated with overall preventive behavior ($r=0.71$, $p<0.001$), with the combined intervention group having 43.3% prevention advocates, significantly higher than single intervention groups. This phenomenon reflects the possible role of "conformity effect" and "social comparison" in collectivist culture, suggesting that athletes' preventive behavior is not only influenced by individual rational choice but may also be moderated by team norms and peer modeling. Three dimensions of training cultural atmosphere—safety-first culture ($\beta=0.35$), prevention value recognition ($\beta=0.29$), and collective responsibility awareness ($\beta=0.24$)—were all significantly associated with intervention effects. Among these, collective responsibility awareness, a dimension rarely addressed in Western research, demonstrated a unique associational pattern in this study, possibly stemming from the Chinese cultural emphasis on "team honor" and "mutual care" traditions.

It is worth noting that the study also observed that peer pressure may show negative associations under specific conditions. When teams overemphasize competitive performance while neglecting health protection, athletes' prevention adherence actually decreased ($\beta=-0.18$, $p<0.05$), revealing the "double-edged sword of collectivism" phenomenon. Multilevel model analysis showed that 28% of preventive behavior variance was explained by team-level factors, a proportion usually below 15% in similar Western studies, highlighting the possible amplification effect of social environmental factors in the Chinese cultural context. These findings provide important references for constructing localized prevention systems, but also remind us that associations between cultural factors and intervention effects may be influenced by various confounding factors and require further verification in more diverse samples and contexts.

5.3. Theoretical significance of synergistic intervention mechanisms

This study observed synergistic effects between functional training and cognitive education, with a synergistic enhancement index of 1.42, indicating that the integration of the two interventions may produce incremental associations compared to separate effects. This finding is consistent with the reciprocal determinism principle of social cognitive theory, which emphasizes dynamic mutual influences among individual cognition, behavior, and environmental factors. Specifically, improvements in physical function after functional training showed temporal co-occurrence with enhanced self-efficacy, and this change in efficacy beliefs may in turn be associated with improved training adherence, forming a potential positive feedback loop pattern. Cognitive education helped athletes understand injury mechanisms and prevention principles, with enhanced risk awareness after cognitive education being associated with sustained training behavior, potentially increasing the likelihood of functional training transitioning from passive execution to active participation.

Structural equation modeling analysis revealed two possible mediating pathways: intervention→ outcome expectations→self-efficacy→preventive behavior (indirect effect=0.38, 95%CI[0.24, 0.54]) and intervention→risk perception→preventive intention→preventive behavior (indirect effect=0.29, 95%CI[0.16, 0.45]), with both pathways jointly associated with 47.3% of preventive behavior variance. These pathway patterns suggest that functional training may enhance efficacy beliefs and positive outcome expectations by providing mastery experiences and physiological feedback, while cognitive education may activate prevention motivation by raising risk awareness and threat appraisal, with both mechanisms jointly associated with behavioral outcomes through different pathways. However, it must be emphasized that these path analyses are based on cross-sectional and short-term longitudinal data and cannot confirm strict causal chains. Future research needs to employ more rigorous experimental manipulation and longer time intervals to verify these hypothesized mechanisms.

Exploratory results from cross-lagged panel analysis showed possible bidirectional temporal co-occurrence relationships between cognitive changes and behavioral changes, with early cognition having stronger predictive effects on subsequent behavior (β=0.64), while later behavior showed stronger predictive effects on subsequent cognition (β=0.61). This pattern echoes the "reciprocal determinism" perspective in social cognitive theory, suggesting that cognition and behavior may not be a unidirectional linear relationship but rather a dynamic process of mutual promotion and spiral advancement. The combined intervention group exhibited the highest cognitive-behavioral coupling coefficient (0.76), possibly reflecting that receiving both interventions simultaneously is more conducive to establishing coordinated associations between cognition and behavior. These findings provide preliminary evidence for understanding the mechanisms of complex interventions, but due to the exploratory nature of the analyses and sample size limitations, these results require replication verification in independent samples.

6. Conclusion

Based on the social cognitive theory framework, this study systematically examined the associational effects of shoulder functional training and injury cognition education on shoulder injury prevention among Chinese young tennis players, yielding the following five conclusions:

(1) The association between combined intervention and behavioral outcomes was significantly superior to single intervention strategies. The synergistic enhancement index reached 1.42, indicating that the integration of functional training and cognitive education showed a 42% incremental association compared to separate effects. The injury incidence rate in the combined intervention group decreased to 6.7% (compared to 36.7% in the control group), with a preventive behavior maintenance rate of 91.2%. These results support the necessity and potential value of multidimensional interventions and are consistent with the reciprocal determinism principle of social cognitive theory.

(2) Self-efficacy showed a mediation association pattern between intervention and behavioral outcomes, consistent with the social cognitive theory framework. Self-efficacy showed a significant positive correlation with preventive behavior (β=0.67), with the mediating effect accounting for 56.6% of the total effect, of which task self-efficacy association was most critical (mediating effect=0.58). This finding observed correlational patterns between cognitive changes and behavioral changes, supporting the important role of efficacy beliefs in behavior shaping, though the causal direction still requires further verification.

(3) Outcome expectations and risk perception presented a dual cognitive association mechanism of "benefit-seeking and harm-avoidance." Moderate levels of risk perception (3.5-4.2 points) showed the strongest association with behavior promotion effects, while either too low or too high risk perception was associated with lower adherence, presenting an inverted U-shaped association pattern. Outcome expectations significantly moderated the relationship between risk perception and preventive behavior (interaction term β=0.34), with their interaction associated with 47.3% of preventive behavior variance. This pattern aligns with the predictions of protection motivation theory.

(4) Cognitive changes and behavioral changes showed dynamically co-occurring temporal patterns. In the early phase (0-6 weeks), the association between cognitive changes and subsequent behavioral changes was strong (β=0.64); the middle phase (6-12 weeks) showed a reciprocal enhancement pattern; and in the later phase (12 weeks-follow-up), the association between behavioral experience and subsequent cognitive reinforcement strengthened (β=0.61). This temporal sequence pattern provides reference basis for optimizing interventions in stages, but the exact causal direction between cognition and behavior still requires more rigorous experimental designs to verify.

(5) The associational roles of coach support and team atmosphere were prominent in the Chinese cultural context. Team-level factors explained 28% of preventive behavior variance, with coach support level showing a significant positive correlation with intervention effects (β=0.42). When coach support fell below the critical value of 3.65, the association of intervention effects was no longer significant. These findings highlight the importance of considering local cultural characteristics when constructing prevention systems, but the unique role of cultural factors still requires cross-cultural comparative research for further confirmation.

Conflict of interest

The authors declare no conflicts of interest.

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