behavioral sciences

MDPI

Systematic Review

The Effects of Imagery Practice on Athletes' Performance: A Multilevel Meta-Analysis with Systematic Review

Yiran Liu, Shiao Zhao *, Xuda Zhang, Xiaoyu Zhang, Taihe Liang and Ziheng Ning

Faculty of Health Sciences and Sports, Macao Polytechnic University, R. de Luís Gonzaga Gomes, Macao 999078, China; p2417052@mpu.edu.mo (Y.L.); p2417093@mpu.edu.mo (X.Z.); p2417184@mpu.edu.mo (X.Z.); tigerleung4177@gmail.com (T.L.); zhning@mpu.edu.mo (Z.N.)

* Correspondence: zhaoshiao530@gmail.com

Abstract: Imagery, a classic technique in psychological training, is gaining momentum in competitive sports. Despite the increasing use of imagery, its effectiveness remains debated. Robust, data-driven conclusions are still lacking. This study seeks to investigate the effects of imagery practice on enhancing athletic performance and determine the ideal dosage of such practice through a systematic review and multilevel meta-analysis. A comprehensive search across seven databases, including SportDiscus, PubMed, PsycINFO, Web of Science, MEDLINE, MEDLINE Complete, and CINAHL, yielded 23,027 studies. These were initially reviewed for title and abstract using ASReview, followed by full-text screening with Covidence. A total of 86 studies with 3593 athletes (2104 males and 1110 females) were included in this meta-analysis. Our findings indicate that imagery practice enhances athletic performance, encompassing agility, muscle strength, tennis and soccer performance, and is applicable to both tennis and soccer athletes. The efficacy of integrating imagery practice with one or two additional psychological skills trainings (PSTs) surpasses that of imagery practice in isolation. Moderation analysis revealed that engaging in imagery practice for approximately ten minutes, three times weekly over a span of one hundred days, produces the strongest performance gains. This review offers recommendations for athletes regarding the implementation of imagery practice in routine training or prior to competitions, thereby providing empirical evidence to optimize psychological training programs in competitive settings.

Keywords: athletic performance; imagery; athletes; psychological skills training; sports performance

check for updates

Academic Editor: Andrew Soundy

Received: 6 April 2025

Revised: 9 May 2025

Accepted: 13 May 2025

Published: 16 May 2025

Citation: Liu, Y., Zhao, S., Zhang, X., Zhang, X., Liang, T., & Ning, Z. (2025). The Effects of Imagery Practice on Athletes' Performance: A Multilevel Meta-Analysis with Systematic Review. *Behavioral Sciences*, *15*(5), 685. https://doi.org/10.3390/bs15050685

1. Introduction

In the context of elite sports, where marginal performance gains are decisive, psychological skills training (PST) has emerged as a crucial complement to physical conditioning (Reinebo et al., 2024; Toth et al., 2020). The distinction between victory and defeat is increasingly tenuous, with even minor errors potentially resulting in sportsmen forfeiting the championship. During the 2008 Beijing Olympic Games, the average margin between the first and the fourth places in the men's rowing events was 1.34%, while for women, it was only 1.03% (Birrer & Morgan, 2010). Consequently, among the various PST techniques, mental imagery is frequently adopted by athletes (Zakrajsek & Blanton, 2017). However, despite its popularity, systematic and conclusive evidence of its efficacy remains limited, particularly concerning dosage effects and sport-specific applicability.

Mental imagery denotes a multimodal cognitive simulation process that allows for the representation of perceptual information in the mind without actual sensory input

(Munzert et al., 2009; Toth et al., 2020), characterized as a sensory experience that emulates real-life sight, taste, and sound (Anuar & Bahar, 2023). A systematic theoretical framework underpins imagery practice to support its principles. The bio-informational theory posits that narrative imagery elicited by verbal text can activate the brain's associative memory network, prompting individuals to produce corresponding real reaction information, including autonomic or somatic nervous responses (Lang, 1979). Moreover, Carpenter posited that vivid imagery enhances muscle activity and resembles genuine muscle activation, hence facilitating actual motor performance, so this theory is referred to as the psychoneuromuscular theory (Murphy & Jowdy, 1992). These theoretical foundations justify the investigation of imagery's physiological and performance outcomes, which we empirically test via meta-analytic synthesis. However, despite this theoretical backing, the actual effectiveness of imagery practice remains uncertain.

Certain experts assert that employing imagery practice (Morone et al., 2022) or integrating it with physical exercise can augment the efficacy of enhancing athletic performance (Lindsay et al., 2023). Additionally, McCormick et al. (2015) indicated that imagery, self-talk, and goal setting were most advantageous for enhancing athletes' endurance performance, and imagery practice appears to positively influence the enhancement of motor skill performance, including basketball performance (Blumenstein et al., 2018; Fazel et al., 2018), gymnastics performance (Battaglia et al., 2014; Khalaf et al., 2024), tennis performance (Laurent et al., 2024; Nicolas et al., 2025), soccer performance (Amini Farsani et al., 2023; Robin et al., 2020), among others. Moreover, a meta-analysis determined that imagery practice is an excellent method for improving athletic performance; however, this meta-analysis lacks effective exploration of the dose of imagery and includes relatively few articles, requiring further investigation (Simonsmeier et al., 2021). Thus, while the existing evidence suggests that imagery practice holds promise, the methodological constraints and limited scope of past studies highlight the need for more rigorous and comprehensive investigations.

Notwithstanding the increasing data endorsing imagery practice, considerable obstacles persist in its execution. Diverse studies present varying viewpoints on the efficacy of imagery practice in enhancing athletic performance. Recent research asserts that imagery practice, mindfulness training, and PSTP constitute the most effective psychological skills training for enhancing athletes' performance (Reinebo et al., 2024). Nevertheless, upon the exclusion of low-quality studies, including subjective performance outcomes and non-randomized controlled trials, the actual effect of PST diminishes significantly (Reinebo et al., 2024). Furthermore, research indicates that imagery practice based on the physical, environment, task, timing, learning, emotion, and perspective (PETTLEP) model does not enhance the athletic performance of youth soccer players (Quinton et al., 2014). Simultaneously, the impact of imagery practice on athletes' jumping performance is similarly negligible (Avila et al., 2015). Additionally, a meta-analysis revealed that the combination of imagery practice and physical exercise is less helpful in enhancing muscle strength than physical exercise alone (Paravlic et al., 2018). Simonsmeier et al. (2018) suggested that imagery practice appears to provide advantageous effects solely for the athletic performance of elite athletes.

On the other hand, the ideal dosage of imagery practice for athletes remains largely unexamined by experts. Recent studies indicate that imagery practice for four weeks, lasting fifteen minutes per session, three times weekly, appears to yield the most beneficial results for healthy individuals; however, there is insufficient investigation into the ideal dosage of imagery practice for athletes (Itoh et al., 2023; Paravlic et al., 2018). Therefore, a considerable number of studies have also expressed skepticism regarding the effectiveness of imagery practice in enhancing athletic performance, and few studies have systematically evaluated the optimal dosage of imagery practice. A complete study with a large sample size is needed to reach a strong conclusion on the effectiveness of imagery practice.

This study employed a Bayesian multilevel meta-analysis to assess the impact of imagery practice on athletes' motor areas. The primary goal was to determine whether imagery enhances athletic performance. If so, we further explored which performance types benefit the most. We also examined whether combining imagery with other psychological skills training yields greater effects than imagery alone, and whether its effectiveness varies by age, gender, or training dosage. Drawing from current yet constrained studies, we suggest two hypotheses: (1) imagery practice has a positive effect on the motor areas; and (2) the effectiveness of imagery practice increases with longer intervention duration.

2. Method

This research was registered with PROSPERO (CRD420251001510) and complied with the PRISMA reporting guideline (Haddaway et al., 2022). A Bayesian meta-analysis was conducted following a systematic review utilizing Covidence, Python version 3, GRADE-profiler, R version 4.4.3, and GetData Graph Digitizer.

2.1. Eligibility Criteria

Studies were eligible if they met the following criteria based on the PICOS framework. The participants must have been athletes. Athletes of all ages, irrespective of their health status, were included. Studies must be randomized controlled trials including imagery practice as a treatment. The comparator can be either the absence of psychological training (no practice) or other psychological skills training, excluding imagery practice. Outcomes derived from studies must pertain to athletic performance. The language must be English.

Unpublished articles, as well as master's and doctoral theses, were excluded. Studies without accessible data for extraction and non-original studies, such as letters, reviews, or editorials, were excluded from the selection procedure. Studies employing various modalities of the same intervention without a control group were excluded, such as different forms of imagery intervention, including textual or video imagery.

2.2. Information Sources

A thorough search strategy was formulated employing Medical Subject Headings (MeSH) and free-text search phrases to comprehensively examine seven English databases, including SportDiscus, PubMed, PsycINFO, Web of Science, MEDLINE, MEDLINE Complete, and CINAHL, on 22 February 2025. The keywords and subject headings were conclusively determined by deliberation among the three authors (S.Z., Z.N., and Y.L.). Comprehensive search strings for each database are included in Supplementary File S1. A total of 23,027 studies were retrieved utilizing the Covidence online tool and ASReview in Python 3.13.3 (van de Schoot et al., 2021) for the systematic screening.

2.3. Study Selection and Data Collection

All abstracts were evaluated with the assistance of the machine learning technology ASReview to guarantee a rigorous, reproducible procedure (van de Schoot et al., 2021). By training the tool with pertinent and impertinent abstracts, it autonomously forecasts study relevance. ASReview perpetually re-evaluates the complete list of remaining titles or abstracts based on their probability of inclusion. This method diminishes the quantity of abstracts necessitating evaluation by the human reviewer to encompass all eligible papers, hence enhancing the efficiency of the selection process (Holzinger, 2016; Wang et al., 2020). Using a conservative application of the SAFE guideline, inclusion of studies through ASReview was continued until 200 consecutive studies were deemed ineligible (Boetje & Van De Schoot, 2024). In the next phase, two reviewers (S.Z. and Y.L.) used the Covidence online tool recommended by PRISMA to screen full texts (Haddaway et al., 2022). Eligible full-texts were assessed using Extraction 1.0 forms, with discrepancies addressed by the third reviewer (Veritas Health Innovation, 2023).

2.4. Data Items

For each study, the characteristics extracted included authors, publication years, country, intervention, study design, session of imagery practice, sample size, gender, types of athletes, age, training years, and outcomes. The outcomes of motor areas encompassed volleyball performance, tennis performance, swimming performance, subjective performance, sprint, soccer performance, skiing performance, shot performance, rugby performance, racquetball performance, muscle strength, karate performance, jump performance, gymnastics performance, golf performance, field hockey performance, equestrian performance, dance performance, cricket performance, boxing performance, basketball performance, baseball performance, badminton performance, and archery performance.

Data were extracted independently by two authors (S.Z. and Y.L.) using Covidence, with conflicts resolved through discussion with the third author (Z.N.). Data were presented as the means ± standard deviations (M ± SD). We used an online toll called Meta Accelerator to convert data that were not initially in the M ± SD format (Abbas et al., 2024). When data were not presented as exact numbers, Get Data Graph Digitizer (Getdata-Graph-Digitizer, 2020) was used to extract data from graphs.

2.5. Risk of Bias Assessment

The risk of bias for all the included studies was evaluated independently according to the standards specified in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins et al., 2011). Two authors (S.Z. and Y.L.) assessed the included studies through the Cochrane risk of bias (ROB2) criteria in RCTs within Covidence. Seven areas of bias were evaluated: (1) random sequence generation; (2) allocation concealment; (3) blinding of the participants and personnel; (4) blinding of the outcome assessment; (5) incomplete outcome data; (6) selective reporting; and (7) other bias. The risk of bias was classified as low, unclear, or high. Following separate evaluations, the writers achieved consensus through deliberation. The final data were documented in an Excel template and subsequently entered into R software 4.4.3 to generate risk-of-bias summary graphs utilizing the robvis package (McGuinness & Higgins, 2021). Studies exhibiting more than two but fewer than four areas designated as unclear-risk were categorized as having moderate overall risk.

Furthermore, funnel plots were created utilizing the PublicationBias package (Braginsky et al., 2019) to identify publication bias within the included studies. The plots illustrate both affirmative and non-affirmative studies as round dots positioned on either side of the funnel's central axis, with a black diamond denoting the total effect size. The grey diamond represents the overall estimate obtained from the non-affirmative research. By configuring the favor_positive parameter to TRUE, the study concentrated explicitly on the bias towards positive outcomes, facilitating a more lucid comprehension of any potential bias in the literature favoring noteworthy discoveries. Evaluating the symmetry of the data points aids in identifying the existence of publication bias. The Egger test was performed via the rma.mv function inside the metafor package. The *p*-value less than 0.05 indicates the presence of potential bias risk. The S-value, derived from the PublicationBias package, indicates the strength of publication bias required to nullify the meta-analytic effect (Mathur & VanderWeele, 2020).

2.6. Certainty in Evidence

The quality of evidence in the results of athletic performance was assessed using the GRADE approach, which evaluates the risk of bias, inconsistency, indirectness, and imprecision of effect estimates (Balshem et al., 2011). The GRADE approach classifies the quality of evidence as high, moderate, low, or very low.

2.7. Statistical Analysis

Bayesian mixed-effects models implemented in the brms package (Bürkner, 2018) in R 4.4.3 were used to analyze variation in effect sizes. We fitted models supposing a normal distribution and incorporated random effects for within-study ID and between-study ID to address within-study and between-study heterogeneity in each outcome based on two formulas:

$$I^2_{within} = \frac{\tau^2_{withID}}{total\_variance} \times 100$$
$$I^2_{between} = \frac{\tau^2_{betweenID}}{total\_variance} \times 100 \quad (1)$$

Weakly informative Cauchy priors (mean = 0, SD = 1) were employed for the random effects. The athletic performances were analyzed and categorized based on the types of imagery strategies (imagery alone or imagery practice paired with other psychological skills training), categories of athletes, and athletic performance outcomes. Four models were applied to each set of athletic performance data:

(1) Null model to estimate the overall effect sizes. We fitted models on the full dataset for athletic performance.
(2) Imagery model. We categorized imagery practice according to its distinct characteristics. The first type included imagery practice that was not integrated with other psychological skills training, whereas the second type consisted of psychological skills training packages (PSTPs) that incorporated imagery practice. Secondly, a comparison was made between these two forms of imagery practice and other psychological skills training, or the absence of psychological training (no practice).
(3) Performance model: we categorized the derived athletic performance results according to their characteristics.
(4) Athlete model: athletes were categorized according to the type of sport they participated in.

Each model was estimated using four Markov chains, each running for 10,000 iterations. To evaluate the convergence of the Markov chains, we relied solely on the Rhat statistic. Rhat assesses the ratio of between-chain to within-chain variance, where values close to 1 suggest satisfactory convergence (Bürkner, 2018). This metric provides a reliable assessment of convergence, ensuring that chains with Rhat values near 1 have thoroughly explored the posterior distribution, thereby enhancing the reliability of model inference. Bayes factors (BFs) (Makowski et al., 2019) were calculated using the reciprocal of the Savage–Dickey density ratio, implemented through the bayesfactor_parameters function in the bayestestR package. BF > 10 indicates strong evidence in favor of the effect (Kass & Raftery, 1995). For complex hierarchical models, the 95% high-density interval (HDI) (Kruschke & Liddell, 2018) offers a direct and assumption-free representation of the most credible posterior values. This stands in contrast to p-values and confidence intervals, which rely on additional assumptions.

2.8. Moderation Analysis

In this study, moderation analysis was performed using the brms package in R, incorporating eight moderator variables: age, gender, training experience (in years), disease status, competitive level, sport type (team or individual), PST experience, and the number of PST in PSTPs (PSTP types). PSTP types refer to the number of psychological skills trainings integrated alongside imagery practice within a training package, categorized as combinations of two, three, or four techniques in total (i.e., imagery plus one, two, or three additional psychological strategies). PST experience was defined as whether the athlete had prior exposure to psychological skills training interventions. Three moderators, including imagery practice duration (in days), frequency (sessions per week), and intensity (minutes per session), were examined to determine the optimal dosage of imagery practice for enhancing athletic performance. The analysis was conducted within a Bayesian framework, enabling the estimation of effect sizes while accounting for measurement error and the hierarchical structure of the data.

Furthermore, to evaluate the influence of various moderators on model performance, we initially created a null model devoid of any moderators and subsequently developed distinct models integrating individual moderators. Bayesian R-squared values were calculated for each model using the bayes_R2 function in the brms package to measure the proportion of variance elucidated. To assess the explanatory capacity of models with and without moderators, we illustrated the density distributions of R-squared values. This method offers a clear depiction of the impact of incorporating moderators on model fit, facilitating a more straightforward comparison between the null model and the models that include certain moderators.

3. Results

The results include six parts, namely, study selection, characteristics of the included studies, quality assessment, meta-analysis with four models, moderation analysis, quality grade, and publication bias.

3.1. Study Selection

The flow chart can be found in Figure 1. From seven databases, 23,027 articles were retrieved and imported into Endnote software for filtering out duplicates; 7931 studies were marked as duplicates and removed automatically by Endnote. The remaining 15,096 articles were imported into the ASReview tool for initial screening, including screening titles and abstracts. With the assistance of machine learning models, a total of 1524 articles were screened, and 234 articles were included in the full-text screening. After full-text screening, 157 articles were excluded due to various reasons, and 77 articles were included in this meta-analysis. Through the citation searching method, an additional 9 articles were included. Ultimately, a total of 86 articles were included in the meta-analysis.

3.2. Characteristics of the Included Studies

The detailed characteristics of each included study can be found in Supplementary File S2. We included 86 studies and 3593 athletes, comprising 1110 females and 2104 males, with 379 athletes lacking gender information (D. Bedir & Erhan, 2021; Blumenstein et al., 2018; Budnik-Przybylska et al., 2024; Kanthack et al., 2013; Laurent et al., 2024; Lebon et al., 2010; Plakoutsis et al., 2025; Robin et al., 2019, 2020, 2022a; Rodgers et al., 1991). Except for seven studies designed as randomized crossover studies (Daneshfar et al., 2022; Guillot et al., 2015; Rumeau et al., 2023, 2024; Simonsmeier et al., 2018; Taylor & Shaw, 2002; Winter & Collins, 2013), all other studies were randomized parallel-group trials. In 24 studies, a combination of imagery practice and other psychological training was used as intervention methods (28%). Thirty-four studies were from Europe (40%), 17 studies were from America (20%), 16 studies were from Asia (19%), 6 studies were from Africa (7%), and 5 studies were from Oceania (6%). Ten studies did not provide age information (Budnik-Przybylska et al., 2024; Chungath et al., 2022; Gray, 1990; Hashmi et al., 2020; McAleney et al., 1990; Prasomsri et al., 2024; Predebon & Docker, 1992; Smith et al., 2008; Suedfeld et al., 1993; Wagaman et al., 1991).

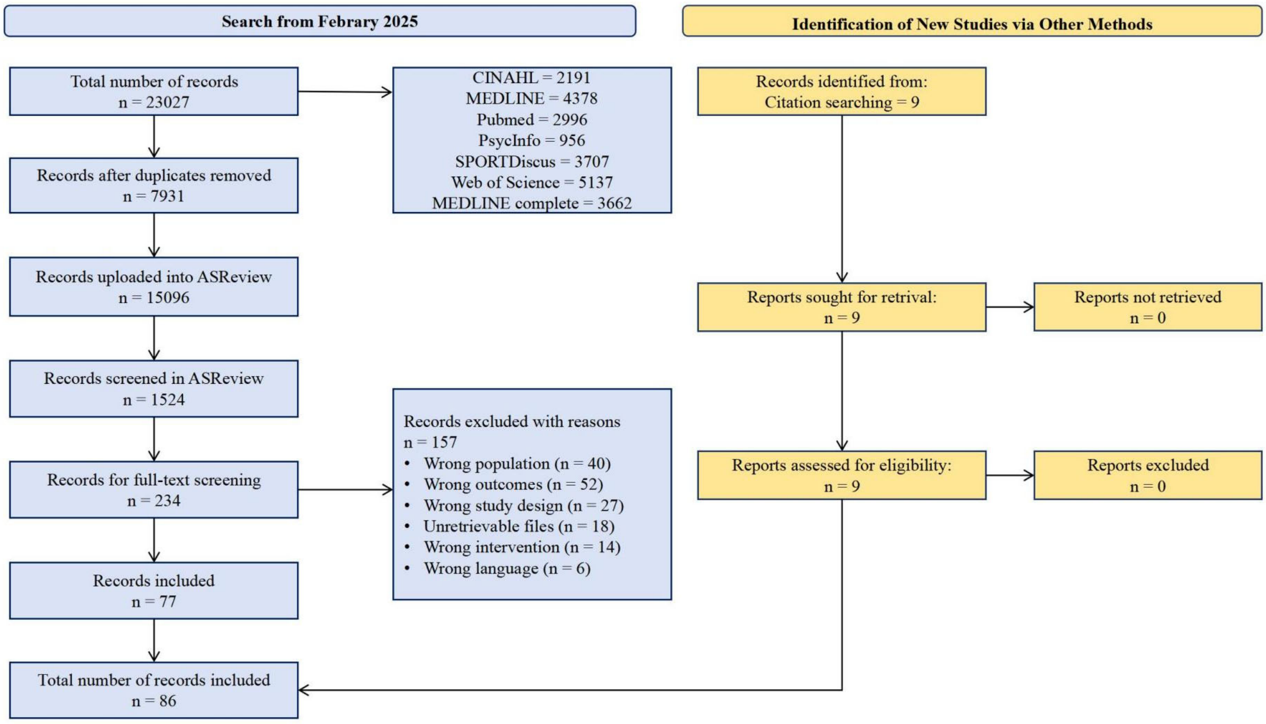

Figure 1. PRISMA flow chart for the identification of the included studies.

3.3. Quality Assessment

The risk-of-bias summary can be found in Figure 2, and the specific risk-of-bias graph for each study can be found in Supplementary File S3. Due to the wrong randomized method, such as stratified randomization, some studies were marked as high-risk (6%) (Björkstrand & Jern, 2013; Callow et al., 2006; Hardy & Callow, 1999; Lu et al., 2020; Marshall & Gibson, 2017). More than 80% of the studies did not mention the use of blinding and were therefore rated as unclear-risk. Due to incomplete data, two articles were rated as high-risk (2%) and two articles were rated as medium-risk (2%). Overall, over half of the literature was rated as unclear-risk, thus weakening the robustness of the data results.

3.4. Meta Analysis

The meta-analysis was divided into four sections. The Section 1 included the null model, followed by the imagery model, the performance model, and the athlete model. The detailed results in each model can be found in Supplementary File S4. The convergence of the Markov chain across all four models was effectively assessed using the Rhat parameter value in the results. The Rhat value in all the outcomes was approximately 1.0. Consequently, we did not present the results of Markov chain convergence in the article.

3.5. Null Model

In the null model, the overall effect size was calculated for athletic performance. Eighty-six studies with 3593 athletes were included in the null model. The forest plot can be found in Supplementary File S5. The Bayesian meta-analysis showed a statistically significant effect [μ(SMD): 0.5, 95% CI: 0.34–0.67; HDI: 0.34–0.67; BF: 12.41], with moderate between-study heterogeneity and low within-study heterogeneity [within I2: 34.06%, between I2: 65.94%]. Imagery practice can effectively improve athletes' performance. Figure 3 shows the cumulative probability and posterior density distribution of SMD, τ_{within} and $\tau_{between}$ in athletic performance.

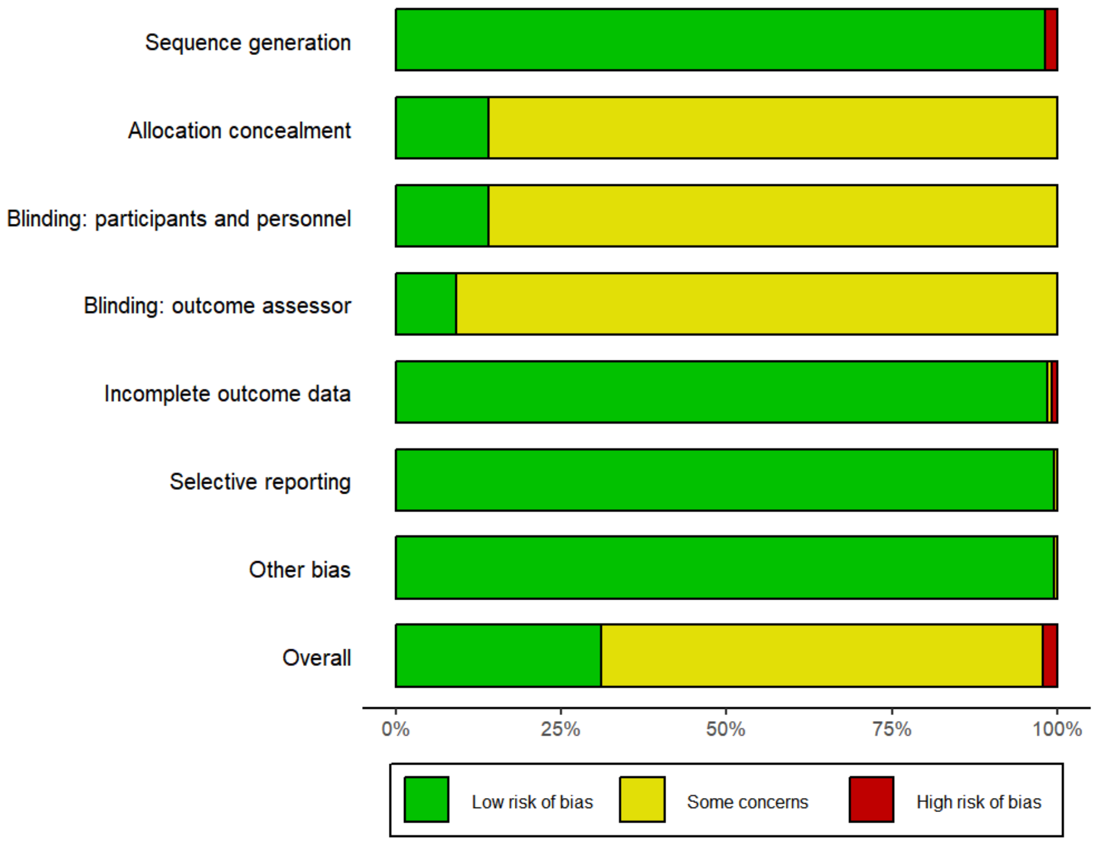

Figure 2. Risk-of-bias summary.

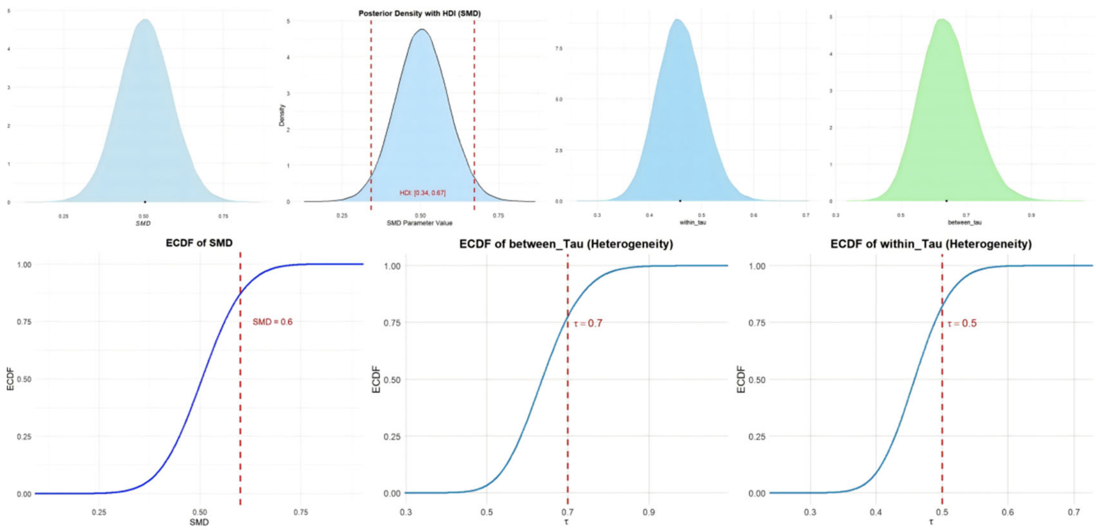

Figure 3. The cumulative probability, HDI distribution, and posterior density distribution (SMD, τ_{within} and $\tau_{between}$) in athletic performance.

3.6. Performance Model

In the performance model, 28 results on different sports performance indicators were presented, as shown in Figure 4 of the forest plot. However, only four indicators of athletic performance showed statistical significance, including agility [μ(SMD): 0.86, 95% CI: 0.18–1.55; HDI: 0.17–1.53; BF: 1.41], muscle strength [μ(SMD): 0.66, 95% CI: 0.13–1.18; HDI: 0.12–1.17; BF: 1.01], tennis performance [μ(SMD): 0.9, 95% CI: 0.41–1.4; HDI: 0.39–1.38; BF: 18.94] and soccer performance [μ(SMD): 0.63, 95% CI: 0.15–1.12; HDI: 0.16–1.12; BF:

1.52], with low within-study heterogeneity and moderate between-study heterogeneity [within I2: 9.5%, between I2: 57.79%].

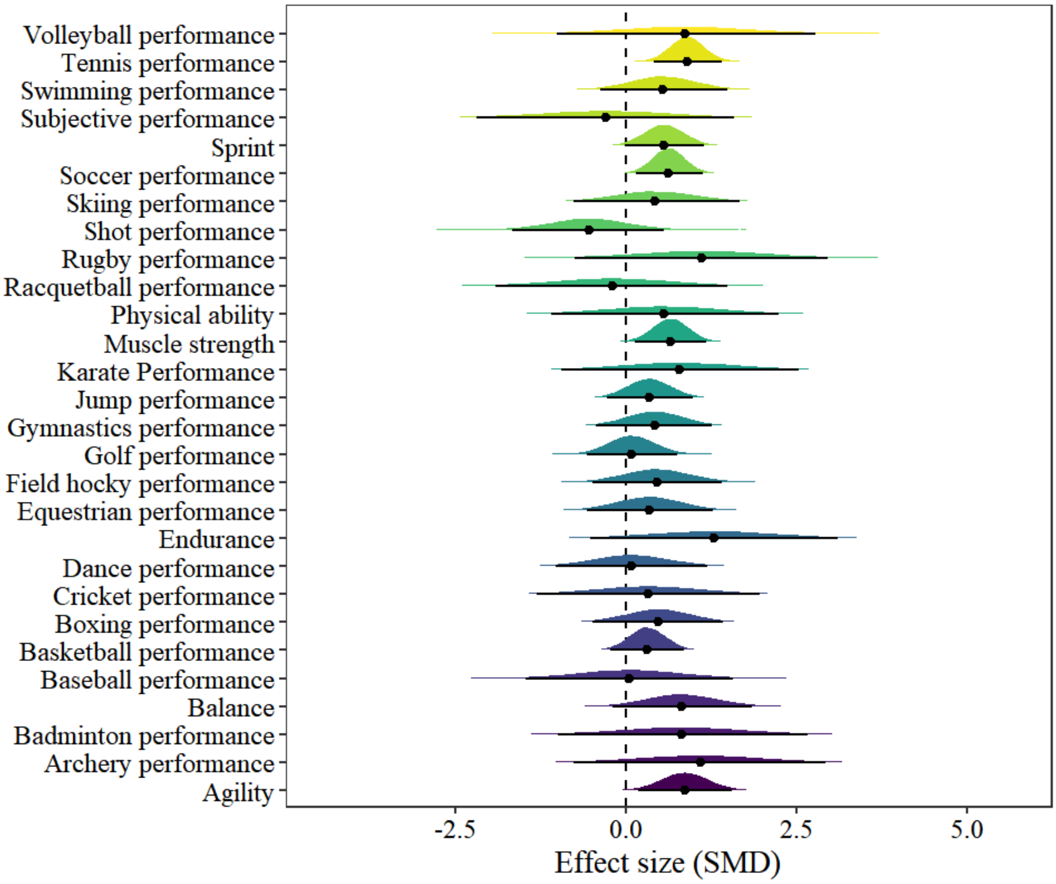

Figure 4. The forest plot in the performance model.

3.7. Imagery Model

In the imagery model, 13 pairs of comparisons were included. The forest plot can be found in Figure 5. Only four pairs of comparisons showed statistical significance, including imagery practice vs. no practice [μ(SMD): 0.5, 95% CI: 0.31–0.68; HDI: 0.31–0.69; BF: 4480], imagery practice vs. PSTP [μ(SMD): −0.8, 95% CI: −1.12 to −0.48; HDI: −1.12 to −0.48; BF: 327.4], PSTP vs. feedback [μ(SMD): 1.53, 95% CI: 1.05–2.01; HDI: 1.04–2; BF: 28,300] and PSTP vs. no practice [μ(SMD): 0.95 95% CI: 0.66–1.23; HDI: 0.66–1.22; BF: 15,900], with low within-study heterogeneity and high between-study heterogeneity [within I2: 2.11%, between I2: 80.29%].

3.8. Athlete Model

In the athlete model, 27 types of athlete results were included. The forest plot can be found in Figure 6. Only two types of athletes showed statistical significance, including tennis players [μ(SMD): 1.12, 95% CI: 0.67–1.57; HDI: 0.68–1.57; BF: 663.9] and soccer players [μ(SMD): 0.58, 95% CI: 0.17–1.01; HDI: 0.17–1.01; BF: 1.96], with low within-study heterogeneity and moderate between-study heterogeneity [within I2: 10.1%, between I2: 53.89%].

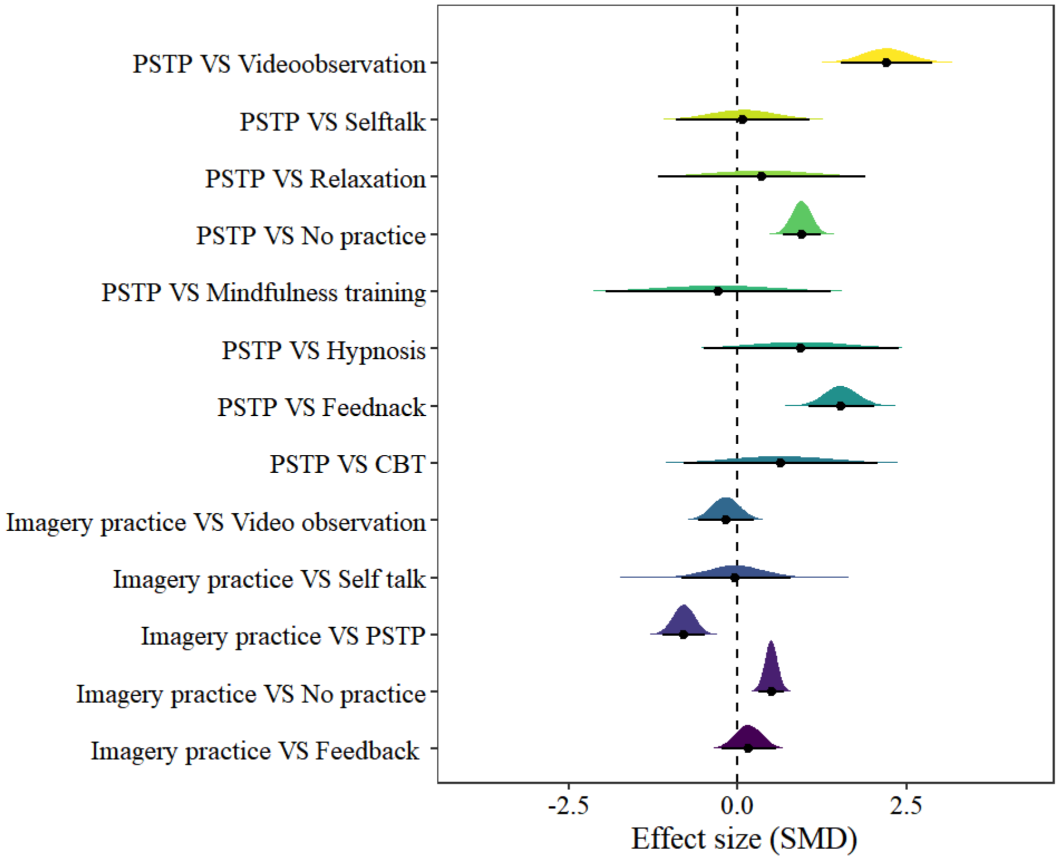

Figure 5. The forest plot in the imagery model.

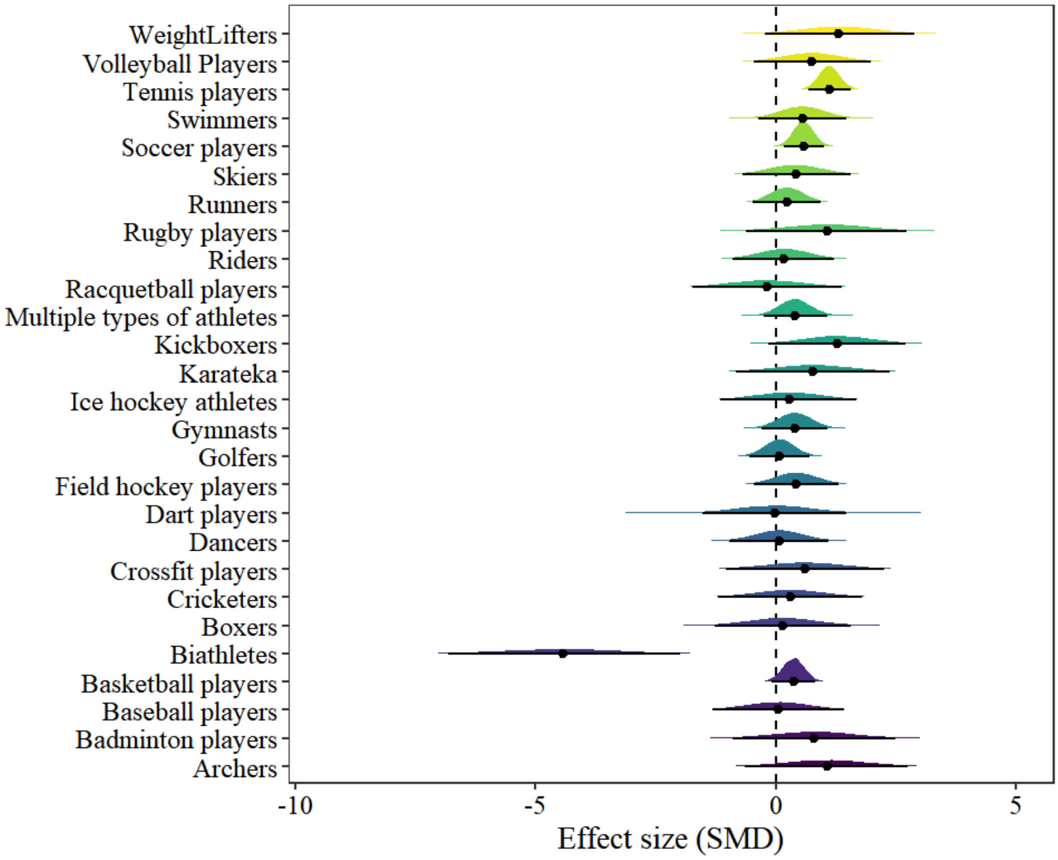

Figure 6. The forest plot in the athlete model.

3.9. Moderation Analysis

Seven moderators regarding athletes' characteristics, including age, gender, training experience (in years), disease status, competitive level, sport type (team or individual), and PST experience, and four moderators concerning imagery dose and PSTP dose encompassing imagery practice duration (in days), frequency (sessions per week), intensity (minutes per session) and the number of PST in PSTPs were included in the moderation analysis. Regarding the moderation analysis of population characteristics, the charts can be found in Supplementary File S6. The detailed results of the moderation analysis by population characteristics can be found in Table 1. The results in the gender model show that imagery practice had a worse effect on women than men (estimates: −0.01, −0.01 to −0.001). In the disease model, imagery practice had a better effect on intervening in healthy athletes (estimates: 0.42, 0.33–0.52). In the competitive level model, imagery practice is more effective for amateur athletes (estimates: 0.54, 0.35–0.74). In the sport type model (team or individual), imagery practice had a stronger effect on individual sports (estimates: 0.51, 0.38–0.65). In the PST experience model, imagery practice was more effective for athletes without psychological skills training experience (estimates: 0.45, 0.22–0.69).

Table 1. Detailed results of the moderation analysis by population characteristics.

	Moderator	Estimate	l-95% CI	u-95% CI	R^2	l-95% CI	u-95% CI
1	Gender	−0.01	−0.01	−0.001	0.59	0.5	0.69
2	Age	0.01	−0.02	0.02	0.65	0.56	0.73
3	Training years	−0.02	−0.08	0.03	0.69	0.52	0.82
4	Disease (TRUE)	0.86	−0.62	2.37	0.66	0.58	0.73
5	Disease (FALSE)	0.42	0.33	0.52	0.66	0.58	0.73
6	Competitive level (amateur)	0.54	0.35	0.74	0.67	0.59	0.74
7	Competitive level (elite)	−0.14	−0.37	0.09	0.67	0.59	0.74
8	Competitive level (mix)	−0.49	−1.03	0.05	0.67	0.59	0.74
9	TI (individual sports)	0.51	0.38	0.65	0.66	0.58	0.73
10	TI (team sports)	−0.15	−0.36	0.04	0.66	0.58	0.73
11	TI (mix)	−0.32	0.7	0.05	0.66	0.58	0.73
12	PST experience (TRUE)	−0.12	−1.09	0.86	0.76	0.62	0.87
13	PST experience (FALSE)	0.45	0.22	0.69	0.76	0.62	0.87
14	Base	0.43	0.33	0.52	0.66	0.58	0.73

PST: psychological skills training; TI: team or individual sports.

The optimal modality appeared to be moderated by PST experience. Compared with the base model (R^2 = 0.66), R^2 was higher for the PST experience model (R^2 = 0.76), training years model (R^2 = 0.69), and the competitive level model (R^2 = 0.67). R^2 in the disease model (R^2 = 0.66) was the same as that of the base model. R^2 in the gender model (R^2 = 0.59) was lower than in the base model. The R^2 density plot can be found in Supplementary File S5.

Four moderators regarding the imagery dose were added to the moderation analysis.

Regarding the duration of imagery practice, 100 days of imagery practice [coefficient estimates: 0.62, 95% CI: 0.28–0.93] were more effective than 50 days [coefficient estimates: 0.47, 95% CI: 0.32–0.61] and 20 days of practice [coefficient estimates: 0.38, 95% CI: 0.23–0.54]. The regression plot can be found in Figure 7.

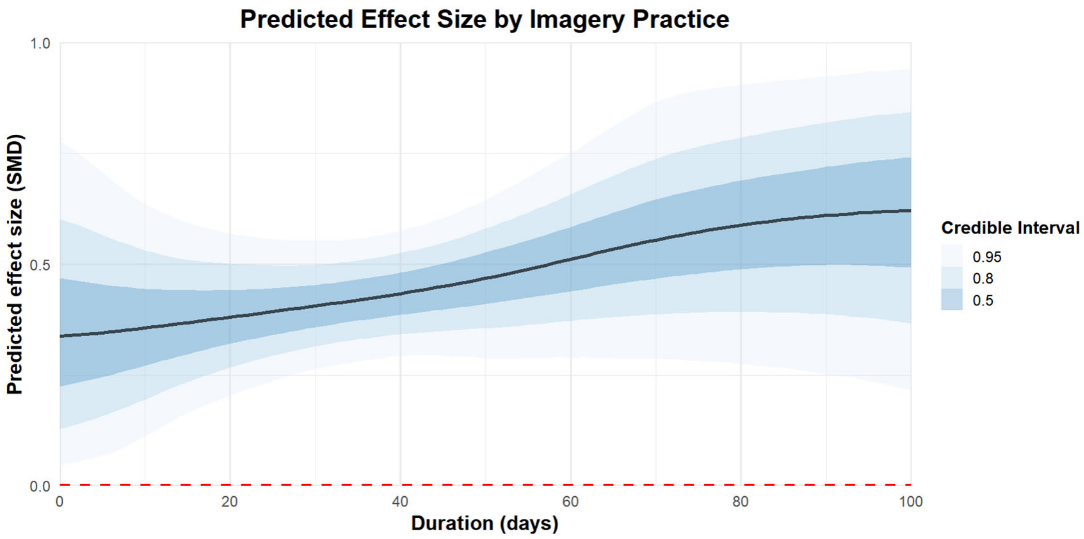

Figure 7. The moderation analysis by duration (days).

Regarding the weekly frequency of imagery practice, the effect of practicing three times a week [coefficient estimates: 0.59, 95% CI: 0.42–0.75] was better than practicing once a week [coefficient estimates: 0.09, 95% CI: −0.24 to 0.42] or seven times a week [coefficient estimates: −0.13, 95% CI: −0.85 to 0.55]. The regression plot can be found in Figure 8.

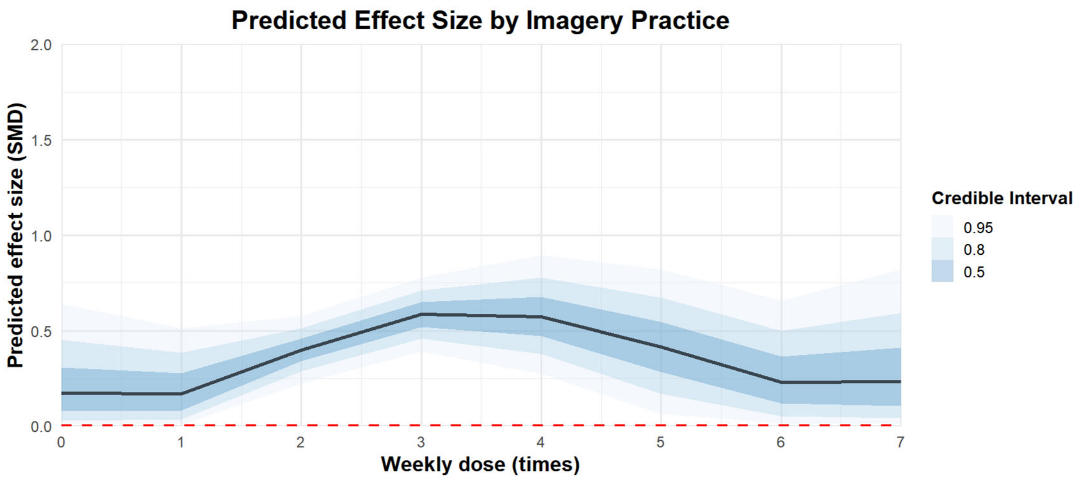

Figure 8. The moderation analysis by weekly frequency (times).

Regarding the intensity of imagery practice, practicing for ten minutes at a time [coefficient estimates: 0.51, 95% CI: 0.34–0.7] was more effective than practicing for twenty [coefficient estimates: 0.22, 95% CI: −0.02 to 0.45], thirty [coefficient estimates: 0.26, 95% CI: −0.02 to 0.53], or forty-five minutes [coefficient estimates: 0.93, 95% CI: −0.1 to 2.11]. The regression plot can be found in Figure 9.

Regarding the number of PSTs included in PSTPs, the effect of combining three psychological skills trainings [coefficient estimates: 0.82, 95% CI: 0.37–1.37] was better than that of two [coefficient estimates: 0.55, 95% CI: 0.31–0.79] or four [coefficient estimates: 0.73, 95% CI: 0.11–1.37]. The regression plot can be found in Figure 10.

Because the model of the number of PSTs included in PSTPs only included data from PSTPs, R^2 of this model was excluded from comparison with other models. Thus, the optimal modality appeared to be moderated by the weekly frequency. Compared with the base model (R^2 = 0.55), R^2 was higher for the duration model (R^2 = 0.61), the weekly frequency model (R^2 = 0.62), and the intensity model (R^2 = 0.59). The R^2 density plot can be found in Supplementary File S6. The detailed results of the moderation analysis by imagery dose can be found in Table 2.

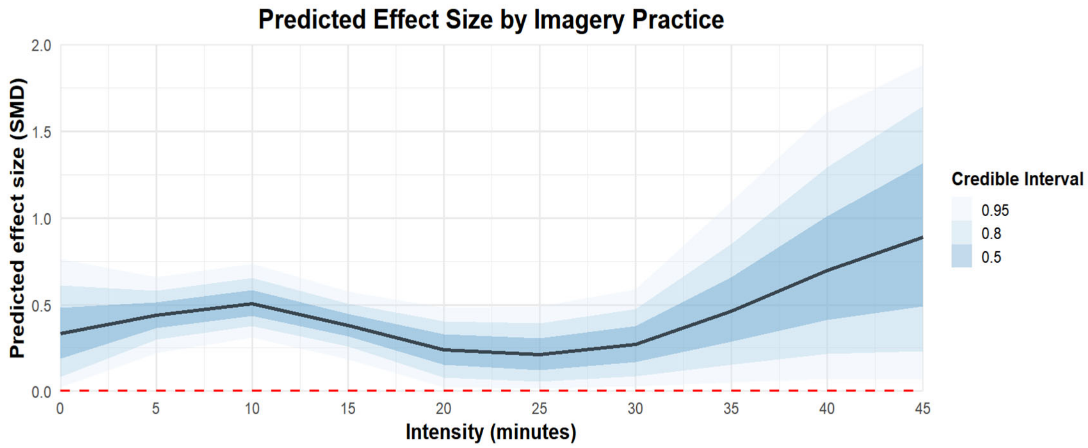

Figure 9. The moderation analysis by intensity (minutes).

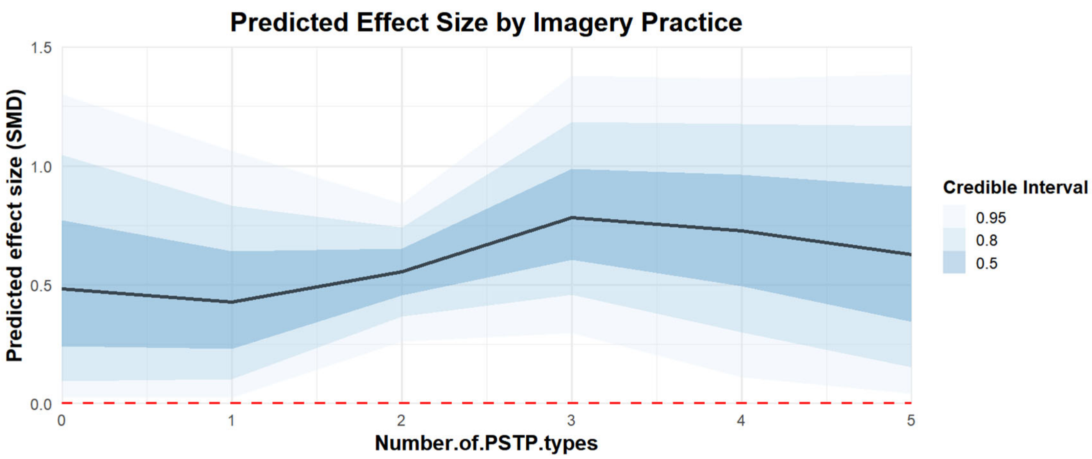

Figure 10. The moderation analysis by the number of PSTs in PSTP.

Table 2. Detailed results of the moderation analysis by imagery dose.

	Moderator	Type	Estimate	l-95% CI	u-95% CI	R^2	l-95% CI	u-95% CI
1	Duration	20 days	0.38	0.23	0.54	0.61	0.48	0.72
2	Duration	50 days	0.47	0.32	0.61	0.61	0.48	0.72
3	Duration	100 days	0.62	0.28	0.93	0.61	0.48	0.72
4	Weekly frequency	Once a week	0.09	−0.24	0.42	0.62	0.47	0.75
5	Weekly frequency	Three times a week	0.59	0.42	0.75	0.62	0.47	0.75
6	Weekly frequency	Seven times a week	−0.13	−0.85	0.55	0.62	0.47	0.75
7	Intensity	10 min	0.51	0.34	0.7	0.59	0.45	0.72
8	Intensity	20 min	0.22	−0.02	0.45	0.59	0.45	0.72
9	Intensity	30 min	0.26	−0.02	0.53	0.59	0.45	0.72
10	Intensity	45 min	0.93	−0.1	2.11	0.59	0.45	0.72
11	PSTP types	2 PSTs	0.55	0.31	0.79	0.79	0.67	0.88
12	PSTP types	3 PSTs	0.82	0.37	1.37	0.79	0.67	0.88
13	PSTP types	4 PSTs	0.73	0.11	1.37	0.79	0.67	0.88
14	Base	NA	0.36	0.27	0.46	0.55	0.43	0.66

PSTP: psychological skills training package.

3.10. Quality Grade in Each Outcome

The quality grade in athletic performance was based on the sample size, results of the meta-analysis, and quality assessment to assess the risk of bias, inconsistency of results, indirectness, and imprecision of effect estimates. The results showed that the quality grade in the results of athletic performance was low because of the potential risk of bias and moderate heterogeneity. The plot can be found in Figure 11.

Imagery practice for Athletic performance

Patient or population: patients with Athletic performance
Settings:
Intervention: Imagery practice

Outcomes	Illustrative comparative risks* (95% CI)		Relative effect (95% CI)	No of Participants (studies)	Quality of the evidence (GRADE)	Comments
	Assumed risk	Corresponding risk				
	Control	Imagery practice				
Athletic performance SMD		The mean athletic performance in the intervention groups was **0.5 standard deviations higher** (0.34 to 0.67 higher)		3593 (86 studies)	⊕⊕⊖⊖ **low**[1,2]	

*The basis for the **assumed risk** (e.g. the median control group risk across studies) is provided in footnotes. The **corresponding risk** (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).

CI: Confidence interval;

GRADE Working Group grades of evidence
High quality: Further research is very unlikely to change our confidence in the estimate of effect.
Moderate quality: Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.
Low quality: Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.
Very low quality: We are very uncertain about the estimate.

[1] Most studies were rated as unclear risk in quality assessment
[2] 50%<I2<75%

Figure 11. Quality grade of athletic performance. ⊕ indicates a positive rating or higher quality of evidence; ⊖ indicates a negative rating or lower quality of evidence.

3.11. Publication Bias

The funnel plots exhibited asymmetry, suggesting a potential risk of bias. The majority of studies were non-affirmative and predominantly clustered on the left side of the graph. Notably, when only nonsignificant studies were included, the pooled effect size became statistically insignificant. The multilevel Egger's test indicated significance ($F_{1,282} = 10.36$, $p = 0.0014$). However, the S-value results indicated that no plausible level of publication bias would nullify the observed effect (S-value = not possible). The funnel plot is presented in Figure 12.

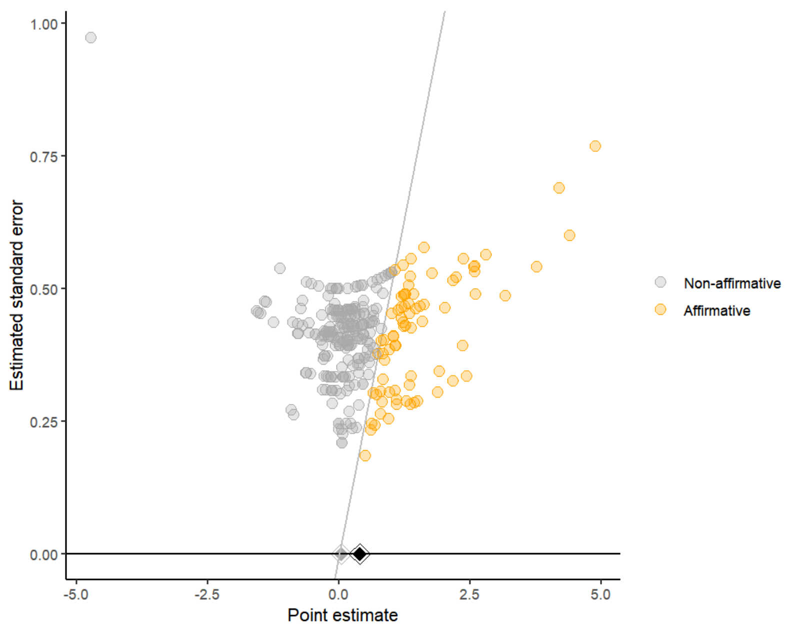

Figure 12. Funnel plot of athletic performance.

4. Discussion

This is the first Bayesian multilevel meta-analysis identifying the optimal dosage and moderated effects of imagery practice on athletic performance. This systematic review and meta-analysis consolidates information about the impact of (1) imagery practice alone or in conjunction with other psychological skills training (PST) on athletic performance, and (2) the dosage of imagery on athletes' performance.

4.1. Summary of the Findings

The results suggest that both imagery practice alone and its combination with other psychological training can enhance athletes' performance. Moreover, integrating imagery practice with additional psychological techniques yields greater benefits compared to using imagery practice or other single psychological training methods, such as video observation and feedback, in isolation. In the performance model, imagery practice could effectively improve athletes' agility, muscle strength, tennis performance, and soccer performance. In the athlete model, the results showed that imagery practice was only effective for tennis players and soccer players. In the moderation analysis, 100 days, three times a week, with approximately ten minutes of imagery practice each time, had a better effect on improving athletes' performance. Additionally, imagery practice was more effective for male amateur athletes who were healthy and had no prior experience with psychological training.

4.2. The Effect of Imagery Practice on Athletic Performance

Data analysis demonstrated that imagery practice positively influences sports performance, particularly in agility, muscle strength, tennis, and soccer performance. Furthermore, imagery practice appears to positively impact tennis and soccer athletes. The enhancement of agility is crucial for athletes, particularly in sports such as basketball and football, which necessitate swift behavioral adaptations to environmental fluctuations (Araújo, 2006). During imagery practice, optimal synaptic connections are activated, playing a crucial role in enhancing agility during movement (Vickers, 2007). Several studies gave supportive evidence (Fekih et al., 2020; McNeil et al., 2021; Prasomsri et al., 2024; Rumeau et al., 2023). McNeil et al. (2021) concluded that, in comparison to no practice, imagery practice can significantly enhance athletes' reaction speed; nonetheless, it appears to be less beneficial than physical training. Moreover, evidence indicates that the combination of imagery practice and physical exercise yields greater enhancements in athletes' agility compared to imagery practice in isolation (Majlesi, 2021; Rozi et al., 2023). This suggests that integrating imagery practice with physical exercise may yield greater positive effects. However, this meta-analysis did not specifically investigate this aspect, as the primary focus of the study was to determine the effectiveness of imagery practice and identify its optimal combination and dosage.

Some research offers evidence that imagery practice can enhance athletes' muscle strength (Alenezi et al., 2023; Cuenca-Martínez et al., 2020; Di Rienzo et al., 2015; Grosprêtre et al., 2018; Lebon et al., 2010). The effectiveness of imagery practice is seemingly contingent upon the surface size of the relevant cortical area associated with the muscle in the primary motor cortex (Lebon et al., 2010). Paravlic et al. concluded that imagery practice is an effective approach for enhancing muscle strength in healthy adults. However, whether combining imagery practice with physical exercise is more beneficial than imagery practice alone remains unclear (Paravlic et al., 2018). This meta-analysis did not find significant improvements in lower limb strength through imagery practice. Some studies suggest that while imagery practice may not significantly enhance jump performance in athletes, there is a noticeable trend toward improvement (Çiftçi & Yılmaz, 2024; Olsson et al., 2008).

Therefore, even in the absence of statistically significant differences, subtle enhancements in technique remain valuable.

The results in the athlete model and the performance model demonstrated that imagery practice significantly enhances performance in tennis and soccer. A multitude of studies arrived at a comparable affirmative conclusion (Amini Farsani et al., 2023; Björkstrand & Jern, 2013; Fortes et al., 2019; Guillot et al., 2015; Nicolas et al., 2025; Robin et al., 2024). Some evidence gives the explanation that interior images may yield valuable insights for angle estimation, which is essential for tennis serve performance (Glisky et al., 1996). Robin and Dominique determined that imagery practice can substantially enhance tennis performance, encompassing forehand, backhand, volley quality, and service efficacy; however, there is a deficiency of further research on imagery practice specifically for female tennis players (Robin & Dominique, 2022). Furthermore, internal imagery appears to be particularly beneficial for tennis players, with several scholars supporting its effectiveness in enhancing performance in closed, goal-directed tasks (Dana & Gozalzadeh, 2017). This provides a robust explanation for the positive effectiveness of imagery practice in tennis performance.

On the other hand, imagery practice has also been shown to enhance soccer performance. Rhodes et al. found that imagery is effective in improving penalty kick accuracy. However, while the PETTLEP model does not support long-term improvements, the motivational approach of functional imagery training (FIT) has been found to facilitate sustained performance enhancements (Rhodes et al., 2020), and FIT can also enhance soccer athletes' grit (Rhodes et al., 2018). FIT appears to be a suitable imagery intervention for soccer players. However, some evidence suggests that PETTLEP imagery practice can enhance goalkeepers' spatial anticipation during penalty kicks (Amini Farsani et al., 2023). Moreover, studies have shown that cognitive-specific imagery interventions can enhance soccer skill performance in youth athletes, with younger athletes experiencing greater benefits from imagery training (Munroe-Chandler et al., 2012). Therefore, while we can currently confirm that imagery practice can improve soccer players' performance, further research is needed to identify the optimal type of imagery practice. Additionally, the lack of statistical significance in other athletic performance results does not imply that imagery practice is entirely ineffective—such as in sprinting. Even a one-second difference in sprint times can be significant, so the small improvements that imagery practice may offer in other areas should not be overlooked. Some evidence suggests that imagery practice can enhance repetitive sprinting ability (Rumeau et al., 2023).

Combining imagery practice with other psychological training has been shown to be significantly more effective than imagery practice alone. Several studies provide supporting evidence for this approach (D. Bedir & Erhan, 2021; Hidayat et al., 2023; Robin et al., 2022a, 2022b). Research has shown that the combined use of self-talk and imagery practice can enhance athletes' motor skills, improve athletic performance (Hidayat et al., 2023), and significantly increase muscle strength, particularly in kickboxers (Slimani et al., 2017). Gmamdya et al. concluded that the integration of imagery practice with feedback, video observation, and regular physical exercise significantly enhances athletic performance (Gmamdya et al., 2023). However, recent studies have suggested that combining virtual reality with imagery practice has a more significant impact on shooting performance and muscle activation than the combination of imagery practice and video observation (D. Bedir & Erhan, 2021; F. Bedir et al., 2025). Therefore, combining imagery practice with various psychological skills training appears to produce inconsistent beneficial effects. Virtual reality (VR), as an emerging and promising technology, has garnered significant attention in the field of sports. More research is needed in the future to explore the most effective imagery practice methods tailored to athletes.

4.3. The Dose–Response Relationship of Imagery Practice and Athletic Performance

The results indicated that imagery practice lasting around ten minutes, three times a week, over the course of one hundred days, had the most significant positive impact on athletes' performance. Several studies provide supporting evidence for this. From a broader perspective, Driskell et al. suggested that the benefits of mental practice diminish with longer durations, and that an optimal practice length of approximately 20.8 min is ideal for PST (Driskell et al., 1994). Secondly, regarding imagery practice, a meta-analysis suggested that increasing the number of sessions enhances the effectiveness of imagery practice for athletes (Simonsmeier et al., 2021), and four weeks, three times a week, fifteen minutes of imagery practice each time are more beneficial for improving muscle strength in healthy adults (Paravlic et al., 2018). This aligns with our results; however, it appears that the optimal dosage of imagery practice may depend on the type of motor performance. For instance, the ideal imagery intervention duration for muscle development in healthy adults seems to be around four weeks, which differs from the overall dosage recommended in our study.

Moreover, our findings indicated that the integration of imagery practice with additional psychological training yielded superior outcomes, and it was optimal to combine one or two types of psychological training to achieve the most effective results. The most popular combinations of imagery practice include imagery practice with self-talk (Cumming et al., 2006; Robin et al., 2022a, 2022b), video observation (Çiftçi & Yılmaz, 2024; Cuenca-Martínez et al., 2020; Lin et al., 2022; McNeill et al., 2020; Shimada et al., 2019), video observation and feedback (Gmamdya et al., 2023), and VR (D. Bedir & Erhan, 2021). However, the optimal combination of imagery practice remains unclear, and further research is needed to provide solid and robust evidence in the future.

Finally, through moderation analysis, we found that imagery practice seems to have a poor effect on female athletes. Some studies provide supporting evidence (Blakeslee & Goff, 2007; Grosso et al., 2024; Simonsmeier et al., 2018). Robin et al. concluded that in the current research on imagery practice, the representation of female athletes is relatively limited (Robin & Dominique, 2022). Consequently, subsequent research should emphasize gender differences in imagery practice to yield more substantial and comprehensive conclusions.

4.4. Strengths, Limitations, and Future Directions

This was the inaugural Bayesian multilevel meta-analysis that comprehensively examined the ideal athlete groups suitable for imagery practice, identified the specific performance metrics that can be enhanced through imagery practice, and delineated the optimal dosage of imagery practice appropriate for this athlete population. It provided more substantial and thorough evidence for the prospective implementation of psychological skills training in sports.

However, several limitations must be addressed. First, there is moderate between-study heterogeneity in the null model, with an overall between-study heterogeneity of around 60%. This heterogeneity decreased somewhat in the performance and imagery models, suggesting that it was partly due to differences in performance indicators and partly due to variations in imagery intervention types. The failure to classify the types of imagery practice in this study contributed to some of the between-study heterogeneity, which in turn reduced the reliability of the results. Second, there was some degree of publication bias, which diminished the quality and reliability of the findings. Third, the inclusion of numerous small-sample studies ($n < 20$) may have contributed to both heterogeneity and publication bias. Additionally, certain athlete groups, such as CrossFit athletes and equestrian athletes, were underrepresented. Fourth, we focused solely on the dosage of imagery practice and did not explore the optimal dosage when combining multiple psychological training methods. Fifth, we did not differentiate between the types of imagery interventions, and the optimal type of imagery practice remains unknown. Sixth, in the dose analysis, a trend toward positive effects was observed with imagery practice lasting over forty minutes. However, due to a lack of further research, the effectiveness of imagery practice lasting more than forty minutes remains uncertain.

Finally, although weekly informative priors were used, effect estimates might still have been influenced by prior specifications. Future work may consider sensitivity analyses with varying priors. High-quality randomized controlled trials with large sample sizes should be conducted in the future to further establish robust evidence on the effects of imagery practice on athletic performance and its optimal dosage. Moreover, exploring the integration of VR-based imagery or AI-guided PST customization may further enhance training personalization and transferability.

5. Conclusions

This study provides compelling evidence that imagery practice significantly enhances athletic performance, particularly in agility, muscular strength, and in tennis and soccer domains. The integration of imagery with one or two psychological skills trainings outperforms standalone imagery. Notably, the optimal dosage—ten minutes per session, three times per week, over 100 days—demonstrated the most robust effect. Through a Bayesian multilevel meta-analysis, this research contributes methodologically rigorous insights into the effect of heterogeneity and moderator structures of psychological skills training. The findings of this study support our hypotheses, demonstrating that imagery practice enhances athletic performance and that a longer duration of practice yields more pronounced effects.

These findings hold direct implications for designing personalized mental training programs, particularly for healthy, amateur athletes without prior PST experience. Coaches and sport psychologists are encouraged to adopt structured, time-efficient imagery protocols informed by this dosage evidence.

Future research should explore (a) the interaction between imagery modalities and motor task types, (b) comparative effectiveness of various PST combinations, and (c) gender-based differences in psychological responsiveness.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/bs15050685/s1.

Author Contributions: S.Z. conceived the study design and initiated the research. S.Z. and Y.L. drafted the manuscript, while S.Z., Y.L., X.Z. (Xuda Zhang), and Z.N. critically revised the manuscript and approved the final version. S.Z., Y.L., X.Z. (Xiaoyu Zhang), X.Z. (Xuda Zhang), T.L. and Z.N. were responsible for manuscript compilation and data retrieval. S.Z. conducted the data analysis. Y.L. is the guarantor. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No new data were created or analyzed in this study.

Acknowledgments: We sincerely appreciate all the students and professors who contributed to this meta-analysis.

Conflicts of Interest: The authors declare no conflicts of interest.

References

Abbas, A., Hefnawy, M. T., & Negida, A. (2024). Meta-analysis accelerator: A comprehensive tool for statistical data conversion in systematic reviews with meta-analysis. *BMC Medical Research Methodology*, *24*(1), 243. [CrossRef] [PubMed]

Alenezi, M. M., Hayes, A., Lawrence, G. P., & Kubis, H.-P. (2023). Influence of motor imagery training on hip abductor muscle strength and bilateral transfer effect. *Frontiers in Physiology*, *14*, 1188658. [CrossRef]

Amini Farsani, M., Shahbazi, M., & Tahmasebi Boroujeni, S. (2023). Improvement in soccer goalkeepers' spatial anticipation during penalty kicks as a result of PETTLEP imagery intervention. *Journal of Imagery Research in Sport and Physical Activity*, *18*(1), 20230022. [CrossRef]

Anuar, N., & Bahar, N. (2023). Imagery training for Malaysian paralympics athletes—An important step towards sports equity. *British Journal of Sports Medicine*, *57*(10), 613–614. [CrossRef] [PubMed]

Araújo, D. (2006). The ecological dynamics of decision making in sport. *Psychology of Sport and Exercise*, *7*, 653–676. [CrossRef]

Avila, B. J., Brown, L. E., Coburn, J. W., & Statler, T. A. (2015). Effects of Imagery on Force Production and Jump Performance. *Journal of Exercise Physiology Online*, *18*, 42–48.

Balshem, H., Helfand, M., Schünemann, H. J., Oxman, A. D., Kunz, R., Brozek, J., Vist, G. E., Falck-Ytter, Y., Meerpohl, J., & Norris, S. (2011). GRADE guidelines: 3. Rating the quality of evidence. *Journal of Clinical Epidemiology*, *64*(4), 401–406. [CrossRef]

Battaglia, C., D'Artibale, E., Fiorilli, G., Piazza, M., Tsopani, D., Giombini, A., Calcagno, G., & Di Cagno, A. (2014). Use of video observation and motor imagery on jumping performance in national rhythmic gymnastics athletes. *Human Movement Science*, *38*, 225–234. [CrossRef]

Bedir, D., & Erhan, S. E. (2021). The effect of virtual reality technology on the imagery skills and performance of target-based sports athletes. *Frontiers in Psychology*, *11*, 2073. [CrossRef]

Bedir, F., Bedir, D., Yılmaz, H. H., Ağduman, F., Şen, İ., Kıyıcı, F., Korkmaz, O. E., Yıldız, M. O., & Çelik, E. (2025). Investigation of the effect of a virtual reality-based imagery training model on muscle activation in athletes. *Frontiers in Psychology*, *16*, 1553327. [CrossRef]

Birrer, D., & Morgan, G. (2010). Psychological skills training as a way to enhance an athlete's performance in high-intensity sports. *Scandinavian Journal of Medicine & Science in Sports*, *20*(s2), 78–87. [CrossRef]

Björkstrand, S., & Jern, P. (2013). Evaluation of an imagery intervention to improve penalty taking ability in soccer: A study of two junior girls teams. *Nordic Psychology*, *65*(4), 290–305. [CrossRef]

Blakeslee, M. L., & Goff, D. M. (2007). The effects of a mental skills training package on equestrians. *The Sport Psychologist*, *21*(3), 288–301. [CrossRef]

Blumenstein, B., Orbach, I., Gelinski, Y., Shemer, Y., Weinstein, Y., & Moran, D. (2018). The effect of mental relaxation and imagery on free throw shooting accuracy among young basketball players. *Journal of Imagery Research in Sport and Physical Activity*, *17*(1), 20210018.

Boetje, J., & Van De Schoot, R. (2024). The SAFE procedure: A practical stopping heuristic for active learning-based screening in systematic reviews and meta-analyses. *Systematic Reviews*, *13*(1), 81. [CrossRef] [PubMed]

Braginsky, M., Mathur, M., & VanderWeele, T. J. (2019). *PublicationBias: Sensitivity analysis for publication bias in meta-analyses* (Version 2.4.0) [Dataset]. Github. [CrossRef]

Budnik-Przybylska, D., Makurat, F., Przybylski, J., & Morris, T. (2024). Effect of imagery training on football players. *Baltic Journal of Health and Physical Activity*, *16*(4), 3. [CrossRef]

Bürkner, P.-C. (2018). Advanced bayesian multilevel modeling with the R Package brms. *The R Journal*, *10*(1), 395. [CrossRef]

Callow, N., Roberts, R., & Fawkes, J. Z. (2006). Effects of dynamic and static imagery on vividness of imagery, skiing performance, and confidence. *Journal of Imagery Research in Sport and Physical Activity*, *1*(1). [CrossRef]

Chungath, A. F., Sudhesh, N. T., Gupta, S., & Divekar, S. (2022). Efficacy of a video modeling and imagery-controlled trial intervention in a non-western adolescent population: A case study. *Case Studies in Sport and Exercise Psychology*, *6*(S1), S1-24–S1-37. [CrossRef]

Cuenca-Martínez, F., Suso-Martí, L., Sánchez-Martín, D., Soria-Soria, C., Serrano-Santos, J., Paris-Alemany, A., La Touche, R., & León-Hernández, J. V. (2020). Effects of motor imagery and action observation on lumbo-pelvic motor control, trunk muscles strength and level of perceived fatigue: A randomized controlled trial. *Research Quarterly for Exercise and Sport*, *91*(1), 34–46. [CrossRef]

Cumming, J., Nordin, S. M., Horton, R., & Reynolds, S. (2006). Examining the direction of imagery and self-talk on dart-throwing performance and self efficacy. *The Sport Psychologist*, *20*(3), 257–274. [CrossRef]

Çiftçi, M. C., & Yılmaz, B. (2024). The effect of action observation and motor imagery on jumping and perceived performance. *Frontiers in Psychology*, *15*, 1362976. [CrossRef]

Dana, A., & Gozalzadeh, E. (2017). Internal and external imagery effects on tennis skills among novices. *Perceptual and Motor Skills*, *124*(5), 1022–1043. [CrossRef]

Daneshfar, A., Petersen, C. J., & Gahreman, D. E. (2022). The effect of 4 weeks motor imagery training on simulated BMX race performance. *International Journal of Sport and Exercise Psychology*, *20*(2), 644–660. [CrossRef]

Di Rienzo, F., Blache, Y., Kanthack, T. F. D., Monteil, K., Collet, C., & Guillot, A. (2015). Short-term effects of integrated motor imagery practice on muscle activation and force performance. *Neuroscience*, *305*, 146–156. [CrossRef]

Driskell, J. E., Copper, C., & Moran, A. (1994). Does mental practice enhance performance? *Journal of Applied Psychology*, *79*, 481–492. [CrossRef]

Fazel, F., Morris, T., Watt, A., & Maher, R. (2018). The effects of different types of imagery delivery on basketball free-throw shooting performance and self-efficacy. *Psychology of Sport and Exercise*, *39*, 29–37. [CrossRef]

Fekih, S., Zguira, M. S., Koubaa, A., Ghariani, I., Zguira, H., Bragazzi, N. L., & Jarraya, M. (2020). The impact of a motor imagery-based training program on agility, speed, and reaction time in a sample of young tennis athletes during ramadan fasting: Insights and implications from a randomized, controlled experimental trial. *Nutrients*, *12*(11), 3306. [CrossRef] [PubMed]

Fortes, L. de S., Almeida, S. S., Nascimento-Júnior, J. R. A., Fiorese, L., Lima-Júnior, D., & Ferreira, M. E. C. (2019). Effect of motor imagery training on tennis service performance in young tennis athletes. *Revista de Psicologia del Deporte*, *28*(1), 157–168.

Getdata-Graph-Digitizer. (2020). Available online: http://getdata-graph-digitizer.com/ (accessed on 14 March 2025).

Glisky, M. L., Williams, J. M., & Kihlstrom, J. F. (1996). Internal and external mental imagery perspectives and performance on two tasks. *Journal of Sport Behavior*, *19*, 3–18.

Gmamdya, H., Souissi, M. A., Bougrine, H., Baaziz, M., Guelmami, N., Majdi, B., Robin, N., & Bali, N. (2023). The positive impact of combining motor imagery, action observation and coach's feedback on archery accuracy of young athletes. *Perceptual and Motor Skills*, *130*(5), 2226–2248. [CrossRef]

Gray, S. W. (1990). Effect of visuomotor rehearsal with videotaped modeling on racquetball performance of beginning players. *Perceptual and Motor Skills*, *70*(2), 379–385. [CrossRef] [PubMed]

Grospretre, S., Jacquet, T., Lebon, F., Papaxanthis, C., & Martin, A. (2018). Neural mechanisms of strength increase after one-week motor imagery training. *European Journal of Sport Science*, *18*(2), 209–218. [CrossRef]

Grosso, F., Balzarini, C., Antonietti, A., & Pagnini, F. (2024). Imagining flying increases jumping performance in volleyball players: A pilot study. *Acta Psychologica*, *248*, 104366. [CrossRef] [PubMed]

Guillot, A., Di Rienzo, F., Pialoux, V., Simon, G., Skinner, S., & Rogowski, I. (2015). Implementation of motor imagery during specific aerobic training session in young tennis players. *PLoS ONE*, *10*(11), e0143331. [CrossRef]

Haddaway, N. R., Page, M. J., Pritchard, C. C., & McGuinness, L. A. (2022). PRISMA2020: An R package and Shiny app for producing PRISMA 2020-compliant flow diagrams, with interactivity for optimised digital transparency and Open Synthesis. *Campbell Systematic Reviews*, *18*(2), e1230. [CrossRef]

Hardy, L., & Callow, N. (1999). Efficacy of external and internal visual imagery perspectives for the enhancement of performance on tasks in which form is important. *Journal of Sport and Exercise Psychology*, *21*(2), 95–112. [CrossRef]

Hashmi, S., Akhtar, T., & Hashmi, M. (2020). Effects of PETTLEP imagery technique on precision skills: A study on drag flick in Pakistan hockey. *Journal of Imagery Research in Sport and Physical Activity*, *15*(1), 20200001. [CrossRef]

Hidayat, Y., Yudiana, Y., Hambali, B., Sultoni, K., Ustun, U. D., & Singnoy, C. (2023). The effect of the combined self-talk and mental imagery program on the badminton motor skills and self-confidence of youth beginner student-athletes. *BMC Psychology*, *11*(1), 35. [CrossRef]

Higgins, J. P. T., Altman, D. G., Gotzsche, P. C., Juni, P., Moher, D., Oxman, A. D., Savovic, J., Schulz, K. F., Weeks, L., Sterne, J. A. C., Cochrane Bias Methods Group & Cochrane Statistical Methods Group. (2011). The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ*, *343*(2), d5928. [CrossRef]

Holzinger, A. (2016). Interactive machine learning for health informatics: When do we need the human-in-the-loop? *Brain Informatics*, *3*(2), 119–131. [CrossRef] [PubMed]

Itoh, S., Morris, T., & Spittle, M. (2023). Examining duration in the imagery dose-response relationship. *Journal of Imagery Research in Sport and Physical Activity*, *18*(1), 20220020. [CrossRef]

Kanthack, T. F. D., Bigliassi, M., Vieira, L. F., & Altimari, L. R. (2013). Efeito agudo da imagética no desempenho de lances livres e percepção de autoeficácia em atletas. *Revista Brasileira de Cineantropometria e Desempenho Humano*, *16*(1), 47–57. [CrossRef]

Kass, R. E., & Raftery, A. E. (1995). Bayes Factors. *Journal of the American Statistical Association*, *90*, 773–795. [CrossRef]

Khalaf, H. H., Hassan, M. M., & Ahmed, M. S. (2024). The effect of seven mental training sessions on developing roundoff and back handspring skills on men's artistic gymnastics. *Asian Journal of Sports Medicine*, *15*(4). [CrossRef]

Kruschke, J. K., & Liddell, T. M. (2018). The Bayesian new statistics: Hypothesis testing, estimation, meta-analysis, and power analysis from a Bayesian perspective. *Psychonomic Bulletin & Review*, *25*(1), 178–206. [CrossRef]

Lang, P. J. (1979). A bio-informational theory of emotional imagery. *Psychophysiology*, *16*(6), 495–512. [CrossRef]

Laurent, D., Carien, R., & Robin, N. (2024). Influence of motor imagery modality on first-serve performance in tennis players. *Motor Control*, *28*(4), 377–390. [CrossRef]

Lebon, F., Collet, C., & Guillot, A. (2010). Benefits of motor imagery training on muscle strength. *Journal of Strength and Conditioning Research*, *24*(6), 1680–1687. [CrossRef]

Lin, C.-H., Lu, F. J. H., Gill, D. L., Huang, K. S.-K., Wu, S.-C., & Chiu, Y.-H. (2022). Combinations of action observation and motor imagery on golf putting's performance. *PeerJ*, *10*, e13432. [CrossRef]

Lindsay, R. S., Larkin, P., Kittel, A., & Spittle, M. (2023). Mental imagery training programs for developing sport-specific motor skills: A systematic review and meta-analysis. *Physical Education and Sport Pedagogy*, *28*(4), 444–465. [CrossRef]

Lu, F. J. H., Gill, D. L., Lee, Y.-C., Chiu, Y.-H., Liu, S., & Liu, H.-Y. (2020). Effects of visualized PETTLEP imagery on the basketball 3-point shot: A comparison of internal and external perspectives. *Psychology of Sport and Exercise*, *51*, 101765. [CrossRef]

Majlesi, S. (2021). The effect of video imagery training on soccer skills performance of high school players. *Psychology and Education Journal*, *58*(1), 3184–3194. [CrossRef]

Makowski, D., Ben-Shachar, M., & Lüdecke, D. (2019). bayestestR: Describing effects and their uncertainty, existence and significance within the bayesian framework. *Journal of Open Source Software*, *4*(40), 1541. [CrossRef]

Marshall, E. A., & Gibson, A.-M. (2017). The effect of an imagery training intervention on self-confidence, anxiety and performance in acrobatic gymnastics—A pilot study. *Journal of Imagery Research in Sport and Physical Activity*, *12*(1), 20160009. [CrossRef]

Mathur, M. B., & VanderWeele, T. J. (2020). Sensitivity analysis for publication bias in meta-analyses. *Journal of the Royal Statistical Society Series C: Applied Statistics*, *69*(5), 1091–1119. [CrossRef] [PubMed]

McAleney, P. J., Barabasz, A., & Barabasz, M. (1990). Effects o f flotation restricted environmental stimulation o n intercollegiate tennis performance. *Perceptual and Motor Skills*, *71*(3), 1023–1028. [CrossRef]

McCormick, A., Meijen, C., & Marcora, S. (2015). Psychological determinants of whole-body endurance performance. *Sports Medicine*, *45*(7), 997–1015. [CrossRef]

McGuinness, L. A., & Higgins, J. P. T. (2021). Risk-of-bias VISualization (robvis): An R package and Shiny web app for visualizing risk-of-bias assessments. *Research Synthesis Methods*, *12*(1), 55–61. [CrossRef]

McNeil, D. G., Spittle, M., & Mesagno, C. (2021). Imagery training for reactive agility: Performance improvements for decision time but not overall reactive agility. *International Journal of Sport and Exercise Psychology*, *19*(3), 429–445. [CrossRef]

McNeill, E., Ramsbottom, N., Toth, A. J., & Campbell, M. J. (2020). Kinaesthetic imagery ability moderates the effect of an AO+MI intervention on golf putt performance: A pilot study. *Psychology of Sport and Exercise*, *46*, 101610. [CrossRef]

Morone, G., Ghanbari Ghooshchy, S., Pulcini, C., Spangu, E., Zoccolotti, P., Martelli, M., Spitoni, G. F., Russo, V., Ciancarelli, I., Paolucci, S., & Iosa, M. (2022). Motor Imagery and Sport Performance: A Systematic Review on the PETTLEP Model. *Applied Sciences*, *12*(19), 9753. [CrossRef]

Munroe-Chandler, K. J., Hall, C. R., Fishburne, G. J., Murphy, L., & Hall, N. D. (2012). Effects of a cognitive specific imagery intervention on the soccer skill performance of young athletes: Age group comparisons. *Psychology of Sport and Exercise*, *13*(3), 324–331. [CrossRef]

Munzert, J., Lorey, B., & Zentgraf, K. (2009). Cognitive motor processes: The role of motor imagery in the study of motor representations. *Brain Research Reviews*, *60*(2), 306–326. [CrossRef] [PubMed]

Murphy, S. M., & Jowdy, D. P. (1992). *Advances in sport psychology: Vol. Imagery and mental practice*. Human Kinetics Publishers.

Nicolas, R., Carien, R., Ouarti, Y., & Laurent, D. (2025). Beneficial effects of imagination of successful action after an actual error on baseline performances in non-expert young tennis players. *Psychological Research*, *89*(1), 23. [CrossRef]

Olsson, C.-J., Jonsson, B., & Nyberg, L. (2008). Internal imagery training in active high jumpers. *Scandinavian Journal of Psychology*, *49*(2), 133–140. [CrossRef]

Paravlic, A. H., Slimani, M., Tod, D., Marusic, U., Milanovic, Z., & Pisot, R. (2018). Effects and dose–response relationships of motor imagery practice on strength development in healthy adult populations: A systematic review and meta-analysis. *Sports Medicine*, *48*(5), 1165–1187. [CrossRef]

Plakoutsis, G., Tsepis, E., Fousekis, K., Christakou, A., & Papandreou, M. (2025). The complementary role of motor imagery on VO2max and lactate in professional football players with grade II ankle Sprains During the return-to-play period. *Applied Sciences*, *15*(2), 820. [CrossRef]

Prasomsri, J., Thueman, B., Yuenyong, P., Thongnoon, C., Khophongphaibun, N., & Ariyawatcharin, S. (2024). Effectiveness of motor imagery on sports performance in football players: A randomised control trial. *Hong Kong Physiotherapy Journal*, *44*(01), 29–37. [CrossRef]

Predebon, J., & Docker, S. B. (1992). Free-throw shooting performance as a function of preshot routines. *Perceptual and Motor Skills*, *75*(1), 167–171. [CrossRef]

Quinton, M. L., Cumming, J., Gray, R., Geeson, J. R., Cooper, A., Crowley, H., & Williams, S. E. (2014). A PETTLEP imagery intervention with young athletes. *Journal of Imagery Research in Sport and Physical Activity*, *9*(1), 47–59. [CrossRef]

Reinebo, G., Alfonsson, S., Jansson-Fröjmark, M., Rozental, A., & Lundgren, T. (2024). Effects of psychological interventions to enhance athletic performance: A systematic review and meta-analysis. *Sports Medicine*, *54*(2), 347–373. [CrossRef]

Rhodes, J., May, J., Andrade, J., & Kavanagh, D. (2018). Enhancing Grit through functional imagery training in professional soccer. *The Sport Psychologist*, *32*(3), 220–225. [CrossRef]

Rhodes, J., May, J., & Booth, A. (2020). Penalty success in professional soccer: A randomised comparison between imagery methodologies. *Journal of Imagery Research in Sport and Physical Activity*, *15*(1), 20200014. [CrossRef]

Robin, N., Carien, R., & Dominique, L. (2022a). Tennis service performance in beginners: The effect of instructional self-talk combined with motor imagery. *Journal of Motor Learning and Development*, *10*(1), 200–211. [CrossRef]

Robin, N., Carien, R., Taktek, K., Hatchi, V., & Dominique, L. (2024). Effects of motor imagery training on service performance in novice tennis players: The role of imagery ability. *International Journal of Sport and Exercise Psychology*, *22*(5), 1070–1082. [CrossRef]

Robin, N., & Dominique, L. (2022). Mental imagery and tennis: A review, applied recommendations and new research directions. *Movement & Sport Sciences-Science & Motricité*, *127*, 57–75. [CrossRef]

Robin, N., Dominique, L., Guillet-Descas, E., & Hue, O. (2022b). Beneficial effects of motor imagery and self-talk on service performance in skilled tennis players. *Frontiers in Psychology*, *13*, 778468. [CrossRef]

Robin, N., Toussaint, L., Charles-Charlery, C., & Coudevylle, G. R. (2019). Free throw performance in non-expert basketball players: The effect of dynamic motor imagery combined with action observation. *Learning and Motivation*, *68*, 101595. [CrossRef]

Robin, N., Toussaint, L., Joblet, E., Roublot, E., & Coudevylle, G. R. (2020). The beneficial influence of combining motor imagery and coach's feedback on soccer pass accuracy in intermediate players. *Journal of Motor Learning and Development*, *8*(2), 262–279. [CrossRef]

Rodgers, W., Hall, C., & Buckolz, E. (1991). The effect of an imagery training program on imagery ability, imagery use, and figure skating performance. *Journal of Applied Sport Psychology*, *3*(2), 109–125. [CrossRef]

Rozi, M. F., Resmana, R., Selviani, I., Okilanda, A., Sumantri, R. J., Suganda, M. A., & Suryadi, D. (2023). Imagery and agility training: How do they affect the reaction ability of futsal goalkeepers? *Physical Education Theory and Methodology*, *23*(3), 325–332. [CrossRef]

Rumeau, V., Grospretre, S., & Babault, N. (2023). Post-activation performance enhancement and motor imagery are efficient to emphasize the effects of a standardized warm-up on sprint-running performances. *Sports*, *11*(5), 108. [CrossRef] [PubMed]

Rumeau, V., Grospretre, S., & Babault, N. (2024). The combination of motor imagery and post-activation performance enhancement is efficient to emphasize the effects of warm-up on sport-specific performance. *Journal of Sports Science and Medicine*, *23*, 834–842. [CrossRef]

Shimada, K., Onishi, T., Ogawa, Y., Yamauchi, J., & Kawada, S. (2019). Effects of motor imagery combined with action observation training on the lateral specificity of muscle strength in healthy subjects. *Biomedical Research*, *40*(3), 107–113. [CrossRef]

Simonsmeier, B. A., Andronie, M., Buecker, S., & Frank, C. (2021). The effects of imagery interventions in sports: A meta-analysis. *International Review of Sport and Exercise Psychology*, *14*(1), 186–207. [CrossRef]

Simonsmeier, B. A., Frank, C., Gubelmann, H., & Schneider, M. (2018). The effects of motor imagery training on performance and mental representation of 7- to 15-year-old gymnasts of different levels of expertise. *Sport, Exercise, and Performance Psychology*, *7*(2), 155–168. [CrossRef]

Slimani, M., Taylor, L., Baker, J. S., Elleuch, A., Ayedi, F. M., Chamari, K., & Chéour, F. (2017). Effects of mental training on muscular force, hormonal and physiological changes in kickboxers. *The Journal of Sports Medicine and Physical Fitness*, *57*(7–8), 1069–1079. [CrossRef]

Smith, D., Wright, C. J., & Cantwell, C. (2008). Beating the bunker: The effect of PETTLEP imagery on golf bunker shot performance. *Research Quarterly for Exercise and Sport*, *79*(3), 385–391. [CrossRef]

Suedfeld, P., Collier, D. E., & Hartnett, B. D. G. (1993). Enhancing perceptual-motor accuracy through flotation REST. *The Sport Psychologist*, *7*(2), 151–159. [CrossRef]

Taylor, J. A., & Shaw, D. F. (2002). The effects of outcome imagery on golf-putting performance. *Journal of Sports Sciences*, *20*(8), 607–613. [CrossRef] [PubMed]

Toth, A. J., McNeill, E., Hayes, K., Moran, A. P., & Campbell, M. (2020). Does mental practice still enhance performance? A 24 Year follow-up and meta-analytic replication and extension. *Psychology of Sport and Exercise*, *48*, 101672. [CrossRef]

van de Schoot, R., de Bruin, J., Schram, R., Zahedi, P., de Boer, J., Weijdema, F., Kramer, B., Huijts, M., Hoogerwerf, M., Ferdinands, G., Harkema, A., Willemsen, J., Ma, Y., Fang, Q., Hindriks, S., Tummers, L., & Oberski, D. L. (2021). An open source machine learning framework for efficient and transparent systematic reviews. *Nature Machine Intelligence*, *3*, 125–133. [CrossRef]

Veritas Health Innovation. (2023). *Covidence systematic review software* [Computer software]. Available online: www.covidence.org (accessed on 15 March 2025).

Vickers, J. N. (2007). *Perception, cognition, and decision training: The quiet eye in action*. Human Kinetics.

Wagaman, J. D., Barabasz, A. F., & Barabasz, M. (1991). Flotation rest and imagery in the improvement of collegiate basketball performance. *Perceptual and Motor Skills*, *72*(1), 119–122. [CrossRef]

Wang, Z., Nayfeh, T., Tetzlaff, J., O'Blenis, P., & Murad, M. H. (2020). Error rates of human reviewers during abstract screening in systematic reviews. *PLoS ONE*, *15*(1), e0227742. [CrossRef]

Winter, S., & Collins, D. (2013). Does priming really put the gloss on performance? *Journal of Sport and Exercise Psychology*, *35*(3), 299–307. [CrossRef]

Zakrajsek, R. A., & Blanton, J. E. (2017). Evaluation of psychological interventions in sport and exercise settings. In R. A. Zakrajsek, & J. E. Blanton (Eds.), *Oxford research encyclopedia of psychology*. Oxford University Press. [CrossRef]