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RESEARCH

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Establishing the minimal important difference of the visual analog scale for assessing exercise-induced fatigue

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Abstract

Background Exercise-induced fatigue is a physiological state characterized by performance decline. The Visual Analog Scale (VAS) is one of the most commonly used subjective methods for evaluating exercise-induced fatigue. However, there is a limited interpretation of how much a change in this method indicates a fatigue status that matters to the exercise performance due to the lack of a well-established minimal important difference (MID).

Methods This study is a secondary analysis of data from three trials. We analyzed individual participant data before and after exercise-induced fatigue. Anchor-based methods were used to determine the MID of the VAS for fatigue, using Countermovement Jump (CMJ) height as an anchor. Specifically, the MID was calculated using mean change, receiver operating characteristic (ROC) curve analysis, and linear regression methods.

Results Data from 71 participants (80.28% male, 22.85 ± 2.51 years), corresponding to 230 person-time measurements, were included in this analysis. The CMJ height fulfilled the requirements to be used as an anchor. MIDs for mean change, ROC curve, and linear regression analysis were 48.51, 44.13, and 43.08, respectively. The Youden's Index indicated that the MID calculated by the mean change method was the most relevant and reliable in distinguishing between fatigued and non-fatigued states.

Conclusions This study establishes a MID (48.51) for interpreting changes in VAS scores. Future research utilizing VAS to assess exercise-induced fatigue should not only consider statistical differences but also examine whether the changes meet the MID threshold to interpret the actual impact of interventions.

Trial registration Chinese Clinical Trial Registry (ChiCTR), Registration Number: ChiCTR2500095599 (Retrospectively registered; registration date: 09/01/2025).

Keywords Fatigue, Visual analog scale, Countermovement jump, Minimal important difference

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Background

Exercise-induced fatigue is a physiological state characterized by a decline in bodily function following intense or prolonged exercise, which is directly reflected by a measurable decline in exercise performance [1, 2]. Exercise-induced fatigue may contribute to many detrimental effects, including increased risk of injury and impaired recovery [3–5]. Accurate identification and recovery from exercise-induced fatigue have become key areas of focus in the field of sports science and exercise health. Effective assessment of fatigue can aid coaches and physiotherapists in designing scientifically sound training programs and recovery protocols to optimize performance and minimize injury risk. Additionally, it allows researchers to more effectively explore and evaluate interventions aimed at managing fatigue.

In the assessment of exercise-induced fatigue, both subjective and objective methods are commonly employed. Subjective methods primarily involve self-report questionnaires, such as the Visual Analog Scale (VAS) [6–8], whichare frequently favored by coaches and researchers due to their ease of use, cost-effectiveness, and ability to capture an individual's perceived experience of fatigue. This makes them particularly useful for immediate and practical applications in both training and competition settings [9]. Objective methods often include assessments of physical performance, physiological indicators, and biochemical markers [10–12]. These methods provide objective data that can directly reflect the physical and physiological status of the athlete, making them valuable tools for accurately monitoring fatigue and recovery. Among these, the Counter-movement Jump (CMJ) test, as an exercise performance test, has become the preferred method for assessing neuromuscular performance and exercise-induced fatigue due to its repeatability, immediacy, and convenience [10, 13].

Among different types of assessment methods, physical performance tests are widely recognized as the primary method for assessing exercise-induced fatigue, given their direct reflection of performance decrements under fatigue [10, 13]. However, their application is often constrained by their tendency to exacerbate fatigue levels during testing, potentially leading to altered physiological responses and elevating the risk of injury or subsequent performance impairment [14]. Moreover, these tests frequently require specialized equipment, limiting their utility in varied settings and immediate fatigue assessments [13]. While physiological and biochemical markers offer objective insights into fatigue states, their effectiveness is restricted by several factors, including high equipment costs, the invasive nature of sample collection, and a lack of universally standardized threshold values that reliably indicate fatigue levels [15, 16]. In response to these limitations, subjective methods (primarily self-report questionnaires) have been widely adopted in sports contexts [17]. They provide a practical, non-invasive, and cost-effective means of assessing fatigue, suitable for real-time monitoring across training and competition scenarios without the need for complex equipment or procedures [18, 19].

The VAS is widely favored for assessing fatigue in training practice and research due to its simplicity and superior sensitivity in detecting changes in exercise-induced fatigue compared to other self-report questionnaires [20]. However, it has inherent limitations like other subjective methods, as it may not always correspond with objective performance or physiological changes, being influenced by individual perception, emotions, and motivation [21]. Researchers and practitioners often view statistically significant increases in VAS scores as indicators of fatigue [18, 19]. In fact, in the field of sports, the primary focus is on the impact of fatigue rather than fatigue itself [22–25]. An increase in perceived fatigue by athletes or participants does not necessarily impair their performance [21]. Only when athletes can no longer sustain their original intensity of exercise is fatigue defined and acknowledged as present [1, 2]. This discrepancy between subjective perception and objective performance raises challenges in interpreting the changes observed in subjective fatigue assessment methods (i.e., VAS). While the statistical significance of changes in subjective fatigue assessments can be estimated using current analytical methods, it is difficult to judge whether these changes have "practical significance" (i.e., affecting athletic performance). The reason for this challenge is that the field of sports science has yet to establish a minimal important difference (MID) for subjective fatigue assessment methods [26–28].

MID refers to the smallest change in a measurement or outcome that is perceived as meaningful or beneficial by researchers or practitioners, beyond mere statistical significance [27, 29]. The determination of MID is typically achieved through the anchor-based method, distribution-based method, expert consensus method, and literature analysis method [29]. Among these, the anchor-based method is the most frequently employed, as it utilizes external indicators that are considered important and meaningful in practice as reference points (i.e., anchor) for assessing significant changes, providing well operationalization and interpretability [30]. The 'anchor' is often determined by objective or subjective indicators that are required to have at least moderate correlations with selected indicators ($r \geq 0.3$) [31]. Previous studies suggested that the results of MID estimation using objective anchors are more stable and reliable than those using subjective anchors [30].

Therefore, we selected an appropriate objective measure (CMJ) as an anchor to determine the MID for subjective fatigue assessment methods like the VAS test.

The aim is to provide a more precise and practically relevant threshold for interpreting changes in subjective fatigue assessments in exercise-induced fatigue research, ensuring that data interpretation reflects practical and impactful changes rather than purely statistical fluctuations. By establishing a well-defined MID in the context of exercise-induced fatigue, this research will provide a reliable benchmark for future exercise practices and studies, allowing researchers and practitioners to determine whether observed changes in subjective fatigue are truly "meaningful", thereby providing reference to the effectiveness of training and recovery strategies for athletes.

Methods

This study is a secondary analysis of data collected from our three previous trials on fatigue assessment and intervention, and it complies with the REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement [32]. The three trials were with ethical approval from the Human Subjects Review Committee of Beijing Sport University (Trial I: 2021004 H; Trial II: 2021163 H; Trial III: 2024237 H), and all procedures were conducted according to the Declaration of Helsinki. All participants signed an informed consent form.

Participants

A sample size of at least 50 participants is required to determine the MID of a self-report measure [33, 34]. Data from 71 healthy and trained participants (14 women and 57 men), including 230 person-times of data in total, were included (Trial I: 125 (36 participants); Trial II: 72 (24 participants); Trial III: 33 (11 participants)). A post-hoc power analysis was conducted using G*Power 3.1.9.7 to assess the statistical power of our study.

The participants were initially recruited for three separate trials. They had 3 to 5 years of training experience without specializing in any particular sport, and their anthropometric characteristics are presented in Table 1. The inclusion criteria were: regular exercise habits, involving engagement in physical activity at least twice a week for one hour or more at a moderate to vigorous intensity level. The exclusion criteria were: no history of lower extremity injury in the six months before the experiment and no cardiovascular, respiratory, and endocrine disease.

Table 1 Characteristics of the study population ($n = 71$)

Demographics	Values
Age (years)	22.85 ± 2.51
Height (cm)	176.27 ± 7.96
Weight (kg)	70.85 ± 11.28
BMI (kg/m^2)	22.66 ± 2.00

Notes: Values are presented as mean ± standard deviation

Study protocol

The experimental procedure followed a standardized four-phase protocol to ensure consistency across all trials: (i) Standardized Warm-up: 5–7 min of dynamic stretching, hip activation drills, and three progressive CMJ practice jumps (50%, 70%, and 90% effort); (ii) Baseline CMJ and VAS Assessment; (iii) Fatigue Models; (iv) Post-Fatigue CMJ and VAS Assessment.

To enhance the generalizability of the results, two types of exercise protocols were conducted as fatigue models in our three trials, including (i) Trial I &II: 60-min cycle ergometer exercises consisting of three 20-min blocks with a 10-s interval between blocks and (ii) Trial III: 15 m running sprints with 20 repetitions and 15s intervals between each sprint. These two exercise protocols were well-established and verified as effective to induce fatigue in previous studies [35–37]. The cycling protocol was conducted at 60% W_{max}, which remained constant throughout the session. The maximum power output (W_{max}) of each participant (200.67 ± 37.14 W, $n = 60$) was determined using a cycle ergometer (Ergoselect 100, Ergoline GmbH, Bitz, Germany). The cycling protocol included (i) a standardized warm-up (3 min at 30 W, 70 ± 5 rpm) and (ii) an incremental test with initial loads of 50 W (males) and 30 W (females), increasing at a rate of 20 W per 2 min until volitional exhaustion.

Each participant completed three or four trials, and there was a minimum resting period of 72 h between two visits to minimize carryover fatigue effects. Each participant was tested at the same time of day across all trials to minimize circadian influences. All participants were instructed to avoid vigorous exercise, alcohol, coffee, supplements, medicines, and any specific recovery treatments within 48 h of each trial period.

Measurements

The VAS test was used to examine the subjective feelings of fatigue [38]. Participants can specify their fatigue level by indicating the location of a continuous 10 cm line between the two endpoints (the starting point represents no fatigue, the endpoint represents extreme fatigue, and the midpoint of the line segment represents moderate fatigue). The distance from the left end to the participant's mark is then measured in millimeters, providing a score ranging from 0 to 100 mm.

The CMJ height is utilized to evaluate neuromuscular performance before and after the induction of exercise-induced fatigue [39]. It was measured by a stationary Kistler three-dimensional force platform (Kistler Instrument AG, Winterthur, Switzerland; collection frequency: 1000 Hz) and Kistler BioWare 4.0.0 software. Participants were instructed to practice the specific movements involved in the CMJ prior to the actual test. During the CMJ, participants assumed a starting position on the force platform, either upright or slightly squatting, with hands on hips. They then performed a rapid and forceful squatting motion, flexing their knees to approximately 90°, followed by an explosive extension to achieve maximum height. Throughout the flight stage of the jump, participants were instructed to extend their knees and keep their hands on their hips to avoid any sideways displacements. When contacting the ground, participants were instructed to land with their toes first. It was emphasized that intentionally bending the abdomen and knees to prolong the time in the air during landing was not allowed. The time in the air, defined as the duration during which the vertical ground reaction force was less than 10 N, was used to calculate jump height [40, 41]. To maximize participant effort, verbal encouragement was provided, and real-time feedback on jump height was displayed throughout the trials. Each participant performed three CMJ tests, and the average of the three was calculated as the final value for analysis.

Statistical analysis

Data analysis was performed with IBM SPSS 27.0, and plots were designed with GraphPad Prism 10.3.0. We calculated the intraclass correlation coefficient (ICC) using a two-way mixed-effects model with absolute agreement (ICC (3,1)) to assess the reliability of measurements across the three trials. Paired t-tests were used to test the significance of changes from pre-test to post-test, and independent samples t-tests were conducted to assess whether the two exercise protocols (cycling and running) produced different effects on changes in CMJ and VAS.

MID was established through anchor-based methods for the VAS [31, 42]. A decrease in CMJ height represents the appearance of exercise fatigue, which was considered to be the anchor by which to evaluate VAS results in this analysis [10]. However, the changes in CMJ height (ΔCMJ) may be caused by random errors introduced by the measurement tool. Thus, we calculated the minimal detectable change (MDC) of ΔCMJ by the distribution-based method and used it as the specific anchor value [43]. Exercise-induced fatigue was considered to occur when the decrease in CMJ height exceeded this specific anchor value.

$$MDC = 1.96 \times \ SEM \times \ \sqrt{2}$$

The correlation between the potential anchor (i.e., CMJ height) and VAS scores was explored using Pearson. Significant and moderate correlations ($r \geq 0.3$) were established as criteria to proceed with the calculation of the MID using anchor-based methods [31]. Then, three statistical methods were used to compute the MID: (i) mean change in the VAS for participants with exercise-induced fatigue (i.e., reached the anchor) [42], (ii) receiver operating characteristic (ROC) curve was calculated using a dichotomous variable, representing whether participants with exercise-induced fatigue or not. The MID value was determined as the optimal cut-off point, where both specificity and sensitivity were maximized, corresponding to the point nearest to the top-left corner of the curve [44], and (iii) linear regression analysis was conducted with the changes in VAS scores (ΔVAS) as the dependent variable and the ΔCMJ as the independent variable [38].

The linear regression model was expressed as follows:

$$\Delta \, VAS = a + b \times \ \Delta \, CMJ + e$$

a, the intercept; *b*, the regression coefficient; *e*, the error term.

The model was fitted using ordinary least squares (OLS) regression to estimate the parameters. This approach ensures that the regression minimizes the sum of squared differences between observed and predicted VAS changes. After calculating the MID, pairwise comparisons were performed using McNemar's test to assess whether the differences in MID values derived from the three methods were statistically significant.

To further assess the effectiveness of each MID value in distinguishing between fatigue states, a random subset of the data was selected for validation. Cross-tabulations were generated to compare the fatigued and non-fatigued groups using each MID as a binary classification variable. Sensitivity and specificity were calculated for each MID, and the one with the most balanced sensitivity and specificity was deemed the most appropriate and reliable. For a more comprehensive evaluation of each MID's discriminatory power, we also calculated Youden's Index (sensitivity + specificity – 1). Additionally, 95% confidence intervals (CI) for sensitivity, specificity, and Youden's Index were estimated using the bootstrap method to assess the stability of these measures.

Youden's index offers a comprehensive measure of test performance by balancing both sensitivity and specificity. The MID with the highest Youden's Index was considered to offer the best balance between true positive and true negative rates and thus was deemed the most relevant and reliable in distinguishing between fatigued and non-fatigued states.

Results

The VAS scores and CMJ height were normally distributed. The ICC for ΔCMJ (0.85, 95% CI: 0.78 to 0.90) and ΔVAS (0.92, 95% CI: 0.88 to 0.94) across the three trials demonstrated excellent reliability and consistency. After the exercise protocols, significant changes were found in VAS scores and CMJ height, respectively ($p < 0.01$), indicating the exercise protocols adopted could

Table 2 Outcome measures before and after the exercise protocols ($n = 230$)

Variables	Baseline	Post-exercise	△	95% CI	*p*-value	ES
VAS	13.23 ± 10.65	58.28 ± 11.83	45.05 ± 10.50	43.69 to 46.42	< 0.01	4.29
CMJ	42.50 ± 11.35	39.87 ± 10.92	-2.62 ± 5.07	-3.28 to -1.96	< 0.01	-0.52

Notes: Values are presented as mean ± standard deviation; △, mean change; ES, Effect sizes; 95%CI, 95% confidence interval

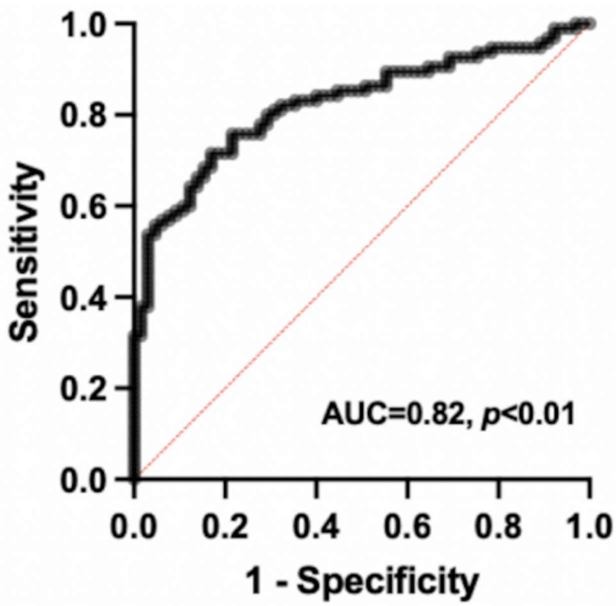

Fig. 1 ROC curve of VAS scores

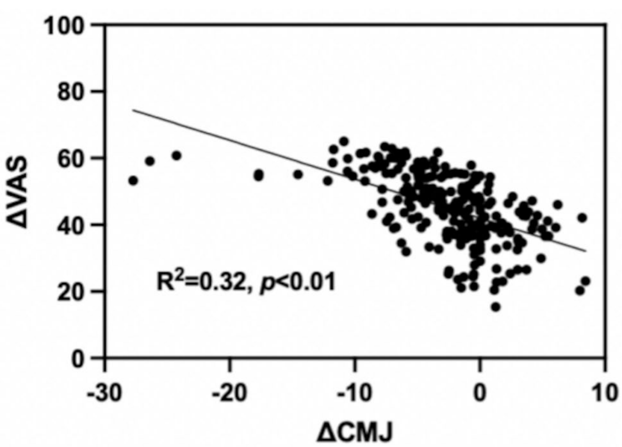

Fig. 2 Correlation between ΔCMJ and ΔVAS

effectively induce fatigue in the participants (Table 2). Meanwhile, post-hoc power analysis confirms that it was adequately powered to detect significant changes in VAS scores (power = 1.00) and CMJ height (power = 0.99).

Independent sample t-tests revealed no statistically significant differences in the ΔCMJ and ΔVAS between two exercise protocols (ΔCMJ: $p = 0.41$; ΔVAS: $p = 0.13$).

ΔCMJ correlated significantly and moderately with ΔVAS (r = -0.56, $p < 0.01$). The MDC for ΔCMJ was 0.93, thus we used a 0.93 cm drop in CMJ height as a criterion for whether the anchor was reached.

We randomly selected 160 data to calculate the MID, and the remaining data (70 person-times) were used to verify the reliability of different MIDs. For the mean change method, 95 person-times of data reached the anchor in total, and the MID for the VAS derived from the mean change methods was 48.51.

Using the ROC curve approach for differentiating between participants with a drop of CMJ height for 0.93 cm resulted in an AUC of 0.82 (95% CI: 0.76 to 0.89, $p < 0.01$) (Fig. 1) and a cut-off value for VAS scores of 44.13 (sensitivity and specificity were both at maximum). Thus, the MID of the VAS determined by this method was 44.13.

The linear regression analysis revealed a statistically significant relationship between ΔCMJ and ΔVAS ($F = 106.27$, $R^2 = 0.32$, $p < 0.01$) (Fig. 2). The model's intercept was 41.99 (95% CI: 40.72 to 43.26, $p < 0.01$), and the regression coefficient for ΔCMJ was − 1.17 (95% CI: -1.39 to -0.95, $p < 0.01$). Residual diagnostics support the validity of the regression analysis (Supplemental Material). The negative regression coefficient confirms that reductions in CMJ are associated with higher VAS scores, reflecting greater fatigue. To determine the MID for VAS, a CMJ threshold of -0.93 cm was applied, yielding an estimated VAS change of 43.08. This value can be considered the MID for VAS based on the regression model.

McNemar's test revealed no statistically significant differences in classification performance between the three MID methods (Mean Change vs. Linear Regression: $p = 0.34$; Mean Change vs. ROC Analysis: $p = 0.21$; ROC Analysis vs. Linear Regression: $p = 0.12$).

A random portion of the data ($n = 70$) was selected for validation, and cross-tabulations were performed to evaluate the effectiveness of each MID in distinguishing between fatigued and non-fatigued states (Table 3). The

Table 3 Validation results of three methods ($n = 70$)

Methods	MIDs	Sensitivity (95% CI)	Specificity (95% CI)	Youden Index (95% CI)
Mean Change	48.51	0.62 (0.50 to 0.73)	0.75 (0.63 to 0.85)	0.37 (0.25 to 0.50)
ROC Analysis	44.13	0.81 (0.70 to 0.90)	0.50 (0.38 to 0.62)	0.31 (0.20 to 0.45)
Linear Regression	43.08	0.86 (0.75 to 0.94)	0.50 (0.38 to 0.62)	0.36 (0.25 to 0.50)

MID of 48.51, derived from the mean change method, showed a sensitivity of 0.62 (95% CI: 0.50 to 0.73), a specificity of 0.75 (95% CI: 0.63 to 0.85), and a Youden's Index of 0.37 (95% CI: 0.25 to 0.50). The MID of 44.13, obtained through ROC analysis, demonstrated the highest sensitivity (0.81, 95% CI: 0.70 to 0.90) but a specificity of 0.50 (95% CI: 0.38 to 0.62), resulting in a Youden's Index of 0.31 (95% CI: 0.20 to 0.45). The Linear Regression method achieved the highest sensitivity (0.86, 95% CI: 0.75 to 0.94) but similarly low specificity (0.50, 95% CI: 0.38 to 0.62), yielding a Youden's Index of 0.36 (95% CI: 0.25 to 0.50).

The MID derived from the mean change method demonstrated the highest Youden's Index, making it the most reliable for distinguishing fatigue states. We calculated the MID values separately for each exercise protocol using the mean change method to evaluate their potential impact on the combined MID value. The MID values for the cycling (49.29) and running (49.53) protocols were close to the combined MID value (48.51), and they demonstrated the same sensitivity (0.62, 95% CI: 0.50 to 0.73), specificity (0.75, 95% CI: 0.63 to 0.85), and Youden's Index (0.37, 95% CI: 0.25 to 0.50). This suggests that the variability in exercise protocols did not significantly influence the MID estimation.

Discussion

To our knowledge, this is the first study to explore the MID of subjective fatigue evaluation in the sports science field. The present study addresses a critical gap in the evaluation of exercise-induced fatigue by proposing a robust approach to determine the MID for the VAS using CMJ height as an anchor. The MID for VAS was determined through three methods: mean change (48.51), ROC analysis (44.13), and linear regression (43.08). The MID derived from the mean change method (48.51) demonstrated the best balance between sensitivity (0.62, 95% CI: 0.50 to 0.73) and specificity (0.75, 95% CI: 0.63 to 0.85), with the highest Youden's Index (0.37, 95% CI: 0.25 to 0.50), making it the most reliable for distinguishing fatigue states.

One key challenge of current studies in using VAS for fatigue evaluation is that significant increases in VAS scores are often interpreted as a reflection of worsening fatigue. However, without a well-defined MID, it is difficult to determine whether such statistically significant increases indicate there is true fatigue that affects the exercise performance (i.e., cannot maintain the original exercise intensity) [29]. Our study provides the first evidence-based MID threshold for VAS in this context, offering a benchmark of 48.51. Only VAS score increases that meet or exceed this "alarm value" could truly impair athletic performance and increase the risk of injury.

Specifically, our findings highlight the utility of CMJ height as a reliable anchor for VAS changes, evidenced by significant correlations between the two measures. The use of CMJ height to assess exercise-induced fatigue aligns with previous studies that have demonstrated its sensitivity in capturing performance declines following fatigue [10, 13]. However, unlike other studies that primarily focused on absolute performance decrements, our analysis integrates MDC to account for random measurement errors, providing a more precise threshold for fatigue evaluation [45].

Integrating multiple anchor-based statistical methods, including methods of mean change, ROC curve analysis, and linear regression, strengthens the reliability of our findings. The regression model further supports the relevance of CMJ as a neuromuscular performance metric for anchoring VAS scores. The negative regression coefficient indicates that decreases in CMJ height, known to reflect neuromuscular fatigue, correspond to higher VAS scores, validating the use of CMJ in fatigue assessments [10]. Consistent with previous studies, the Youden's Index was employed to validate and compare the MID values derived from the three methods [46, 47]. The results demonstrated that the MID value obtained from the mean change method exhibited a higher Youden's Index, indicating its superior reliability in distinguishing between fatigued and non-fatigued states. Although the sensitivity of ROC-derived and regression-derived MID was higher than that derived from the mean change method, their lower specificity suggests more false positive results. In that case, the challenge to interpret the practical significance of the results remains as low specificity means that more changes with no practical significance may be labeled as "significant fatigue". It eventually results in an inability to effectively distinguish those fatigue changes that are truly important from those that are not. The primary purpose of MID is to distinguish statistically significant changes from practically meaningful changes in perceived fatigue, thus ensuring that observed differences are not only statistically valid but also impactful in real-world settings [48]. For this purpose, the MID of the VAS score should maintain a high specificity alongside sensitivity to minimize false positive results, thereby preventing changes without practical significance from being misinterpreted as significant fatigue. Therefore, the MID value determined by the mean change method (i.e., 48.51) may be more reliable and suitable in practical applications.

Despite the strengths of this study, several limitations must be acknowledged. Firstly, the MID value from our study is more applicable to fatigue changes starting from a non-fatigued state rather than assessments that begin at a high level of fatigue. Fatigue changes are not linear, and at higher levels of fatigue, the MID that affects performance may be smaller. Secondly, the exclusive focus on trained, healthy young adults limits the generalizability of the findings to other populations, such as untrained individuals, older adults, or athletes from different sports disciplines. It is necessary to explore how fatigue responses and the reliability of CMJ as an anchor for VAS may differ across these groups. Thirdly, while CMJ height serves as a useful indicator of neuromuscular function, it may not fully capture the multifaceted nature of exercise-induced fatigue, which involves both central (neurological) and peripheral (muscular) components. For endurance or cognitively demanding sports, CMJ may not sufficiently reflect subjective fatigue. Future studies should incorporate multiple anchors consisting of objective performance metrics and subjective fatigue indicators to provide a more comprehensive assessment [49, 50]. Fourthly, the use of CMJ, which primarily measures explosive power, may yield a higher MID compared to endurance activities, which are more sensitive to fatigue defined by the inability to maintain exercise intensity [51]. Developing and integrating fatigue measures that are more sensitive to endurance fatigue would address this issue. Finally, our study only considered immediate post-exercise fatigue, overlooking potential delayed or cumulative effects such as delayed onset muscle soreness (DOMS) or extended recovery periods [52]. A more comprehensive evaluation of fatigue over longer durations, such as across multiple training sessions or competitions, would provide deeper insights into the validity of the derived MID.

Conclusion

This study establishes a MID (48.51) for interpreting changes in VAS scores. By aligning subjective perceptions of fatigue with objective performance decrements, this MID offers an operational threshold that reflects meaningful changes in fatigue, thus improving the interpretability of VAS scores in exercise practice. Future research utilizing VAS to assess exercise-induced fatigue should not only consider statistical differences but also examine whether the changes meet the MID threshold to interpret the actual impact of interventions.

Abbreviations

VAS	Visual Analog Scale
CMJ	Counter-movement Jump
MID	Minimal Important Difference
W_{max}	Maximum Power Output
ΔCMJ	Changes in CMJ height
ΔVAS	Changes in VAS scores
MDC	Minimal Detectable Change
ROC	Receiver Operating Characteristic
OLS	Ordinary Least Squares
DOMS	Delayed Onset Muscle Soreness
CI	Confidence intervals
RECORD	REporting of studies Conducted using Observational Routinely-collected health Data
ICC	Intraclass correlation coefficient

Supplementary Information

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Supplementary Material 1

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Author contributions
The data of trials used in this study were from GD, YC, and YZ. GD and DB conceived the idea for the article. JG and GD wrote the first draft and made the revisions with critical input from QG and DB. JG and YX made all the figures and tables. All authors read and approved the final manuscript.

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Data availability
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Ethical approval was granted through Beijing Sport University (2021004 H/ 2021163 H/ 2024237 H), and informed consent was obtained from all participants in this study. All procedures were conducted according to the Declaration of Helsinki.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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