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Upper limb function, speed climbing performance and musculoskeletal discomfort in professional speed climbers: an exploratory cross-sectional study

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Abstract

Background: Relative pulling strength and shoulder-position-specific force may describe different aspects of speed-climbing capacity. This study examined their associations with competitive performance and distinguished performance profiles from recent upper-limb discomfort.

Methods: This exploratory cross-sectional study included 26 professional speed climbers (17 men, 9 women). The principal comparison was additional weighted pull-up load/body mass versus personal-best 15-m completion time; I/Y/T relative strength was secondary. Recent discomfort and Upper Quarter Y-Balance Test scores were examined exploratorily. Spearman correlations, sex-adjusted rank correlations, permutation tests and bootstrap intervals were reported alongside Benjamini–Hochberg correction. Post hoc sex-specific performance tertiles contextualised pulling and I/Y/T strength distributions.

Results: Relative weighted pull-up load correlated inversely with completion time ($\rho = -0.66$; $q = 0.005$). After sex adjustment, the association remained moderate (partial $\rho = -0.55$; permutation $P = 0.008$; 95% CI −0.83 to −0.06), but did not survive multiplicity correction ($q = 0.077$). IYT mean and lower-side strength showed directionally consistent secondary associations (sex-adjusted partial $\rho = -0.48$ and −0.51; both $q = 0.077$). In the faster within-sex tertile, median additional load/body mass was 1.024 in men and 0.818 in women; median IYT mean strength was 0.204 and 0.210 BW, respectively. Distributions overlapped across bands. Seventeen athletes (65.4%) reported discomfort, most commonly at the shoulder/scapular region or fingers (each 34.6%); no symptom-related comparison survived correction.

Conclusions: Relative pulling capacity and position-specific I/Y/T force provide a cohort-specific descriptive profile of faster athletes. The sex-specific distributions offer an initial reference for repeated strength assessments. Performance capacity and recent symptom burden should be assessed as complementary dimensions.
Keywords: speed climbing; upper limb function; weighted pull-ups; competitive performance; musculoskeletal discomfort

Background

Speed climbing requires athletes to ascend a standardised 15-m route as quickly as possible [1]. During the climb, the upper limbs contribute to gripping, pulling and supporting the body while coordinating with lower-limb propulsion. Electromyographic observations during a 15-m speed climb demonstrate substantial involvement of the finger flexors, biceps brachii and latissimus dorsi [2], while pull-up force–velocity profiling has identified differences in force-production characteristics across climbing disciplines [3]. These findings provide a rationale for investigating upper-limb capacity in speed climbers. However, performance on a rapid, fixed-route task cannot be inferred directly from tests developed for other climbing disciplines.

For applied monitoring, the challenge is to distinguish upper-limb capacities associated with faster climbing from measures that describe musculoskeletal function or symptoms. Scapular function contributes to upper-limb movement and is relevant to shoulder rehabilitation [4], while climbing injury surveys document acute and overuse problems affecting the upper limbs [5]. Assessing completion time and recent symptoms in the same cohort allows both dimensions to be examined alongside upper-limb strength and function.

A multidimensional assessment can sample these distinct aspects of function. Digital dynamometry offers a means of quantifying maximal isometric upper-limb strength [6], and I/Y/T testing quantifies force in specified shoulder positions, providing position-specific information alongside whole-task pulling capacity. The Upper Quarter Y-Balance Test (UQYBT) assesses closed-chain upper-quarter performance; associations with shoulder and trunk strength have been reported in overhead athletes [7]. Its relevance to upper-limb discomfort in speed climbers is considered here as an exploratory question. Weighted pull-ups provide a pulling task used in climbing-specific performance research [8], whereas functional grip measurements vary with hold type and body position [9]. Weighted pull-up load relative to body mass is a

plausible candidate performance correlate because climbing requires athletes to move their own body mass.

Symptom assessment adds a separate dimension. The Oslo Sports Trauma Research Centre Overuse Injury Questionnaire captures physical problems and their effects on participation, training and performance, including problems that do not lead to complete withdrawal from sport [10]. Existing speed-climbing research has associated upper-body strength and power with competitive performance in sex-specific analyses [11]. The question addressed here is how practical strength measures relate to performance and how upper-quarter functional measures relate to recent discomfort in the same professional cohort. Relative weighted pull-up load is evaluated alongside sex as a performance correlate, while UQYBT scores are explored in relation to discomfort location and symptom impact.

Accordingly, this exploratory cross-sectional study examined multidimensional upper-limb function in provincial-level professional speed climbers. The primary objective was to test whether greater weighted pull-up load relative to body mass was associated with shorter personal-best completion time on the standard 15-m route, with sex adjustment assessing the sensitivity of this association. We hypothesised an inverse association between relative weighted pull-up load and completion time. Secondary analyses examined I/Y/T relative strength and grip strength in relation to completion time. Exploratory analyses focused on UQYBT scores in relation to upper-limb discomfort location and questionnaire impact, alongside other functional measures, bilateral asymmetry and within-sex speed–strength discrepancy indices.

Methods

Study Design and Participants

This cross-sectional observational study enrolled 26 provincial-level professional speed climbers (17 men and 9 women; age, 17.85 ± 3.34 years; training history, 4.31 ± 1.74 years) and was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement[12]. Inclusion criteria were systematic speed-climbing training; ability to complete the UQYBT, I/Y/T shoulder isometric strength, grip strength, and weighted pull-up tests; and ability to understand and comply with the questionnaire and maximal-effort testing procedures. Exclusion criteria were an acute upper-limb injury, postoperative recovery, another condition precluding maximal-effort testing, or missing questionnaire or key functional data that could not be verified against original records. All participants

provided written informed consent before testing. The protocol conformed to the Declaration of Helsinki and was approved by the institutional ethics committee of the Hunan Institute of Sports Science (approval number TKSEC202610). Testing was conducted at the Hunan Provincial Physical Fitness Training Center in March 2026. Guardian consent was obtained for participants younger than 18 years.

Multidimensional Upper Limb Function Testing

All tests were completed within the same testing cycle after a standardised warm-up. The sequence was UQYBT, I/Y/T isometric strength, grip strength and weighted pull-ups. Researchers demonstrated each task and allowed practice before formal testing. The tests sampled closed-chain upper-quarter performance, shoulder-position-specific isometric force, handgrip capacity and maximal additional pulling load, respectively (Table 1). I/Y/T force was measured with Kunwei equipment during 3-s maximal efforts alternating between sides. Grip force was measured with a K-Grip dynamometer (KINVENT), with athletes standing, the arm hanging beside the trunk and the elbow extended. UQYBT upper-limb length was measured from C7 to the middle fingertip. Force in newtons was normalised to body weight as $F/(m \times 9.80665)$, where m is body mass in kilograms; additional pull-up load was divided by body mass in kilograms.

Upper Limb Discomfort Locations and Impact Scores

The Oslo Sports Trauma Research Centre Overuse Injury Questionnaire (OSTRC-O), adapted for the sport-specific context of speed climbing, was used to assess athletes' upper limb discomfort and its impact on sport over the past four weeks[10]. The questionnaire focuses on common stress sites in speed climbing—such as the shoulder, elbow, wrist and fingers—recording the location of discomfort, the affected side, and the impact of symptoms on training and competitive performance. The four core questions assess participation in sport, training volume or intensity, competitive performance and pain intensity, respectively. Each question is scored on a scale of 0–25, with a total score ranging from 0 to 100; a higher score indicates a greater impact of upper limb issues on participation in sport and sport-specific performance. This study has only adjusted the descriptions of the sporting context and target areas, whilst retaining the four core questions and the 0–100-point scoring framework; this revised version has not yet undergone independent validity and reliability testing amongst speed climbers.

The total OSTRC score was analysed as a continuous measure of symptom impact. A score of ≥20 was also used as an exploratory binary split; it was not treated as a validated severity threshold. Discomfort

locations were recorded as non-exclusive categories: shoulder/scapular region, fingers, elbows and wrists. These questionnaire outcomes describe recent symptoms and their reported impact, rather than clinical diagnoses or future injuries.

Definition of Competitive Performance

The primary outcome was personal-best completion time on the standard 15-m speed route; a shorter time indicated better performance. Personal best was defined as the fastest time achieved in an official competition during the preceding year. Competition times were supplied by the Hunan Provincial Climbing Team.

Statistical Analysis

Continuous variables are presented as mean ± standard deviation or median (interquartile range), depending on their distribution characteristics; categorical variables are presented as frequencies and percentages. Given the small sample size and the skewed distribution of some indicators, intergroup comparisons for discomfort sites and the OSTRC ≥ 20 score stratification were performed using the Mann-Whitney U test, with Cliff's δ reported; Spearman's rank correlation analysis was used to examine the relationship between best performance, the OSTRC continuous score and the test metrics. Due to the small sample size for elbow and wrist discomfort, these were reported descriptively only. Bilateral asymmetry was expressed as the difference between the left and right sides or as a relative difference. The speed performance and relative strength discrepancy index was calculated within each sex group, defined as the speed z-score (the completion time z-score inverted) minus the strength z-score; a higher value indicates better standardised speed performance relative to standardised strength within this sample.

To assess confounding by sex, completion times and functional measures were rank-transformed and each variable was regressed on sex; correlations were then calculated between the resulting residuals. P values were obtained from 20,000 permutations within sex strata, and 95% CIs were calculated from 10,000 bootstrap samples stratified by sex. Sex-stratified correlations were reported as descriptive sensitivity analyses.

Analyses were organised around weighted pull-up load relative to body mass and personal-best 15-m completion time as the primary comparison. Associations of I/Y/T relative strength and grip strength with completion time were secondary. UQYBT analyses were exploratory, focusing on discomfort location and symptom burden; its completion-time correlations were retained as supplementary exploratory

comparisons. Other discomfort, OSTRC score, asymmetry and speed–strength discrepancy analyses were also exploratory. The Benjamini–Hochberg procedure was applied separately within the analysis domains listed in Additional file 1, Table S1. Complete results for all 66 hypothesis tests are provided in Additional file 1, Table S2. The performance domain included all 16 comparisons, encompassing weighted pull-up, I/Y/T, grip and exploratory UQYBT measures. The primary correlation was accompanied by a percentile 95% CI from 10,000 non-parametric bootstrap samples; sex adjustment provided a sensitivity analysis. All tests were two-sided. $P < 0.05$ indicated nominal significance, and $q < 0.05$ indicated significance after multiplicity correction. Confidence intervals were not adjusted for multiplicity.

To contextualise performance associations, relative weighted pull-up load and body-weight-normalised I/Y/T force were described together across post hoc sex-specific completion-time tertiles (33.33rd and 66.67th percentiles; linear interpolation), providing approximately balanced groups within each sex. No between-band significance tests were performed; cut-points and distribution summaries are provided in Additional file 1, Table S7.

Results

Sample Inclusion and Baseline Characteristics

The study included 26 provincial-level professional speed climbers (17 men and 9 women), with a mean age of 17.85 ± 3.34 years and a mean training history of 4.31 ± 1.74 years. Personal-best completion time averaged 6.59 ± 2.06 s. All core performance, questionnaire and functional variables were complete, and all core analyses included 26 athletes (Table 2).

Multidimensional functional characteristics of the upper limbs

The median UQYBT mean composite score was 90.72% (87.21%, 95.13%). Median IYT mean relative strength was 0.19 BW (0.16, 0.21), median peak grip strength relative to body mass was 0.78 BW (0.71, 0.85), and median weighted pull-up load relative to body mass was 0.87 (0.68, 1.01). Descriptive results for all dimensions and bilateral asymmetry measures are presented in Table 3.

Sites of upper limb discomfort and severity

Seventeen athletes (65.4%) reported upper-limb discomfort during the preceding four weeks. The shoulder/scapular region and fingers were the most frequently reported sites (9 athletes each; 34.6%); one athlete reported elbow discomfort and one reported wrist discomfort. The median OSTRC score was 23.50

(0.00, 34.75), and 17 athletes scored ≥20. These were the same 17 athletes who reported any discomfort (Table 4).

Relationship between sites of discomfort and functional indicators

Athletes with finger discomfort had higher lower-side and mean UQYBT composite scores and lower IYT maximum and T/90 asymmetry than athletes without finger discomfort; absolute between-group effect sizes ranged from 0.49 to 0.57. These differences reached only unadjusted nominal significance (P = 0.020–0.046); all q values were 0.369 after FDR correction. No clear association was observed between shoulder/scapular discomfort and any functional measure (all P ≥ 0.106). Because only one athlete reported elbow discomfort and one reported wrist discomfort, no inferential comparisons were performed for these sites (Table 5).

Speed Performance and Upper Limb Functional Measures

Greater weighted pull-up load relative to body mass was associated with shorter personal-best 15-m completion time ($\rho = -0.66$, $P < 0.001$, $q = 0.005$; bootstrap 95% CI −0.86 to −0.31). After sex adjustment, the association remained moderate (partial $\rho = -0.55$; permutation $P = 0.008$; bootstrap 95% CI −0.83 to −0.06), although it did not meet the multiplicity-corrected threshold ($q = 0.077$). IYT mean and lower-side relative strength showed directionally consistent secondary correlations ($\rho = -0.50$ and −0.51; both $q = 0.055$), with similar sex-adjusted estimates (partial $\rho = -0.48$ and −0.51; both $q = 0.077$). No other performance comparison met $q < 0.05$ (Tables 6 and 7; Fig. 1; Additional file 1, Table S4).

The sex-specific performance bands described these measures on a common performance scale. In the faster male band (n = 6; observed times 4.900–5.090 s), median additional pull-up load/body mass was 1.024 (Q1–Q3 0.944–1.107), alongside IYT mean strength of 0.204 BW (0.191–0.241). Corresponding values in the faster female band (n = 3; 5.820–6.800 s) were 0.818 (0.752–0.878) and 0.210 BW (0.178–0.227). The I, Y and T medians were 0.168, 0.186 and 0.271 BW in men and 0.162, 0.185 and 0.282 BW in women. Pull-up medians decreased across the faster, middle and slower bands within each sex, whereas IYT composite medians were not strictly ordered; both measures showed overlapping distributions (Additional file 1, Table S7).

Bilateral Asymmetry and OSTRC Score

None of the bilateral asymmetry measures was associated with OSTRC score at either the nominal or multiplicity-corrected threshold. T/90 and maximum IYT asymmetry showed negative correlations (ρ = −0.36 and −0.32), whereas correlations for UQYBT bilateral difference and grip asymmetry were close to zero (ρ = 0.06 and 0.10; Table 8).

Speed performance – relative strength difference index and OSTRC score

The OSTRC continuous score was positively correlated with the IYT mean relative-strength discrepancy index (ρ = 0.39, P = 0.049) and showed directionally similar trends for the weighted pull-up and IYT lower-side discrepancy indices. The weighted pull-up discrepancy index was higher in the OSTRC ≥ 20 group than in the OSTRC < 20 group, but the difference was not nominally significant (δ = 0.32, P = 0.196). No discrepancy-index result survived multiplicity correction (all $q \geq 0.470$) (Additional file 1, Table S5).

Sensitivity Analysis

Sex-stratified weighted pull-up correlations were imprecise: $\rho = -0.45$ in men (n = 17; P = 0.069; bootstrap 95% CI −0.87 to 0.11) and $\rho = -0.20$ in women (n = 9; P = 0.609; 95% CI −0.83 to 0.65). Bootstrap sensitivity results for selected effects are provided in Additional file 1, Table S6.

Discussion

Key Findings

This study links upper-limb strength assessment to performance and recent symptoms in the same professional speed-climbing cohort. Relative weighted pull-up load showed the strongest unadjusted performance association; a moderate inverse estimate remained after sex adjustment, although it did not survive multiplicity correction. I/Y/T relative strength showed directionally consistent secondary associations. Describing both measures within the same sex-specific performance bands placed these associations in the context of athletes' observed force profiles. Symptom, asymmetry and discrepancy-index findings provided no corrected evidence for symptom classification, supporting a distinction between performance capacity and symptom burden.

Seventeen athletes (65.4%) reported upper-limb discomfort during the preceding four weeks, most commonly in the shoulder/scapular region and fingers. The OSTRC approach captures problems that affect participation, training, performance or pain even when athletes continue training [10].

Relative Pulling and I/Y/T Strength in Performance Profiling

Relative weighted pull-up load was the clearest candidate performance correlate in the test battery. Its inverse association with completion time is consistent in direction with research on pull-up force–velocity–power profiles [3], upper-body strength and power [11], and force-production differences across climbing levels [13]. After sex adjustment, the estimate remained moderate (partial $\rho = -0.55$; $P = 0.008$; 95% CI −0.83 to −0.06), while $q = 0.077$ indicates uncertainty when considered within the full performance-testing domain.

I/Y/T testing extends this assessment from whole-task pulling capacity to force output at specified shoulder positions. Its mean and lower-side relative-strength associations changed little after sex adjustment (partial $\rho = -0.48$ and -0.51; both $q = 0.077$), making proximal isometric capacity a relevant secondary question. Scapulothoracic motion contributes to upper-limb positioning during elevation and pulling [14], and studies of Y exercises and shoulder rotator strength in climbers provide context for examining this domain [15, 16]. Relating both pulling and position-specific force to body size is appropriate to a task that requires moving the athlete's own mass.

The shared performance bands translate these continuous associations into an initial descriptive strength profile. In the faster male and female bands, median additional pull-up load was approximately 1.02 and 0.82 times body mass, respectively, accompanied by median IYT mean strength of approximately 0.20–0.21 BW. The I, Y and T medians describe how this proximal force profile was distributed across positions (Additional file 1, Table S7).

Coaches could examine overall pulling capacity alongside position-specific force, then evaluate repeated measurements against the athlete's own performance, training exposure and symptoms. IYT medians were not strictly ordered across the performance bands: the male middle band had a slightly higher median than the faster band, and the female slower band a slightly higher median than the middle band. Together with the overlapping distributions, this pattern favours using the profiles to contextualise repeated assessments of individual athletes.

Peak grip strength relative to body mass showed a weaker association with performance than relative weighted pull-up load. Test specificity may contribute to this difference: handgrip dynamometry does not reproduce the hold shapes, finger positions or rapid force application required during speed climbing. Functional grip measurements in climbers vary with holds and body positions [9].

Finger discomfort and functional test performance

Athletes reporting finger discomfort had higher UQYBT scores and lower IYT maximum and T/90 asymmetry, with absolute Cliff's δ values of 0.49–0.57. All corresponding q values were 0.369.

Training exposure and reverse causality are possible explanations for the nominal finger-discomfort findings. Better-performing athletes may accumulate greater sport-specific loading, while symptomatic athletes may change training or rehabilitation before testing. Evidence on intensive training and injury in young athletes provides broader context [17, 18].

The UQYBT samples closed-chain upper-quarter performance [7], whereas finger tendon and pulley loads depend on joint configuration and grip technique [19, 20, 21]. Future work should pair site-specific symptoms with climbing-specific finger tests, clinical assessment and training exposure.

The Relationship between Bilateral Asymmetry and Joint Discomfort

The asymmetry results did not support a consistent positive association with recent symptom burden. Correlations ranged from near zero to negative, and none met the nominal or multiplicity-corrected threshold.

Bilateral differences may reflect task-specific loading, handedness or adaptation as well as functional deficits. Load-distribution studies in climbing illustrate how asymmetry may vary with proficiency [22].

Magnitude-based asymmetry indices also discard which side has the lower value. Overall symptom-side records could not identify the symptomatic region separately when several sites were involved, limiting side-to-side interpretation (Additional file 1, Table S3). Longitudinal studies should retain asymmetry direction and record region-specific symptoms, handedness and task-specific limb use before evaluating whether changes have clinical relevance.

Exploratory Significance of the Speed–Strength Discrepancy

The discrepancy index describes the difference between within-sex standardised speed performance and relative strength. Its association with OSTRC score was nominal for IYT mean relative strength (ρ = 0.39; P = 0.049), but no discrepancy-index result survived multiplicity correction (all $q \geq 0.470$). The

bootstrap 95% confidence interval for that correlation included zero (−0.01 to 0.68). Test–retest studies would clarify whether this sample-dependent index captures stable differences between athletes.The discrepancy index compares within-sex standardised speed performance with standardised relative strength and describes an athlete's position within this sample. Sample composition, measurement error and correlation between the components can affect the index. The nominal IYT association with OSTRC score did not survive multiplicity correction, and its bootstrap interval included zero. Test–retest and prospective studies could establish its stability and relevance for monitoring.

Implications for Training Monitoring

The sex-specific distributions provide an initial reference for contextualising measurements obtained with the same testing protocol.The shared performance bands provide an initial reference for describing overall pulling capacity and position-specific proximal force in athletes assessed with the same protocol. Additional pull-up load/body mass and I/Y/T BW quantify different tasks and should be interpreted separately within that profile. Repeated measurements alongside competition time, training exposure, recovery and symptoms can test whether changes in either domain are useful for monitoring. Site-specific finger assessments and clinical examination could complement symptom reporting in future studies. Repeated measurements could assess whether they add information alongside UQYBT and bilateral asymmetry.

Strengths and Limitations of the Study

This study integrates competitive performance, several upper-limb functional domains and recent symptoms within a specialised cohort of professional speed climbers. Complete core data enabled a consistent comparison across measures without missing-value imputation. The combination of effect sizes, multiplicity correction, bootstrap intervals and sex-adjusted analyses provides a transparent assessment of the strength and precision of the associations. Examining UQYBT and symptom burden exploratorily also broadens the functional profile beyond maximal strength and helps distinguish performance-related capacity from recent discomfort.

The findings provide an initial cohort-specific profile that can guide longitudinal research. Their interpretation should take account of the cross-sectional design, the single-team sample of 26 athletes and the different assessment windows for historical personal-best performance and recent symptoms. Sex-adjusted estimates and infrequent elbow or wrist symptoms warrant confirmation in larger cohorts. The

adapted questionnaire and exploratory ≥20 split describe reported symptom impact; further validation and repeated functional testing alongside training exposure would strengthen their application.

Directions for Future Research

Future research should adopt a multicentre, prospective cohort design, with repeated measurements of upper limb function, training exposure and OSTRC scores over one or more complete training cycles, whilst recording new injuries, medical diagnoses, time off training and the return-to-sport process. Statistical analysis could employ mixed-effects models to examine whether changes in individual athletes' function precede changes in symptoms, thereby distinguishing stable individual differences from short-term risk signals. For finger-related issues, grip-posture-specific finger strength, rate of force development and fatigue indicators should be included; for shoulder function, dynamic scapular kinematics, electromyography or closed-chain rapid strength tests should be incorporated.

The speed–strength discrepancy index first requires evaluation of test–retest reliability, cross-sample comparability and temporal prediction of subsequent symptoms. Future prediction studies would need sufficient prospective data on independent injury events and training exposure, with bootstrap internal validation and validation in an independent cohort. I/Y/T strength, bilateral asymmetry and the discrepancy index are candidates for hypothesis-driven longitudinal monitoring.

Conclusions

Relative weighted pull-up load showed the strongest unadjusted association with faster personal-best 15-m performance, with a moderate inverse estimate remaining after sex adjustment despite not surviving multiplicity correction. Directionally consistent secondary I/Y/T associations and the shared sex-specific performance-band descriptions provide an initial profile of overall pulling capacity and position-specific proximal force in this professional cohort. These distributions offer a reference for repeated strength assessment under the same protocol. Exploratory UQYBT comparisons by discomfort site, bilateral asymmetry associations with OSTRC score and discrepancy-index findings yielded no associations that survived multiplicity correction. Repeated within-athlete assessment could establish whether changes in strength and function track changes in performance and recent symptoms.

List of abbreviations

BM: body mass; BW: body weight; CI: confidence interval; FDR: false discovery rate; IYT: I/Y/T isometric strength test; OSTRC: Oslo Sports Trauma Research Centre; OSTRC-O: Oslo Sports Trauma Research Centre Overuse Injury Questionnaire; STROBE: Strengthening the Reporting of Observational Studies in Epidemiology; UQYBT: Upper Quarter Y-Balance Test.

Declarations

Ethics approval and consent to participate

The study was approved by the Ethics Committee of the Hunan Institute of Sports Science (TKSEC202610) and was conducted in accordance with the Declaration of Helsinki. All participants provided written informed consent before participation. Guardian consent was obtained for participants younger than 18 years.

Consent for publication

Not applicable.

Availability of data and materials

Restrictions apply to the availability of raw participant-derived data to protect participant confidentiality. Aggregated summary data are available from the first author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Peng Liu conceived the study topic and drafted the manuscript. Caihua Fng and Zeyong Xu conducted the testing. Binghong Gao performed the final review of the manuscript. All authors read and approved the final manuscript.

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420 Table 1. Upper limb functional tests and key indicators

Test Name	Test Requirements and Key Indicators
I/Y/T Shoulder Joint Isometric Strength Test	Kunwei equipment was used for 3-s maximal isometric efforts alternating between sides. Recorded peak force was retained. Shoulder-abduction positions were I/180°, Y/135° and T/90°. Force in newtons was divided by body weight in newtons. Exact model, fixation, trunk posture, trial count and rest require verification.
Upper Limb Y-Balance Test	The subject assumes the standard one-arm push-up support position, with the non-supporting hand pushing the slider in three directions: medially, inferior-laterally and superior-laterally. The best distance achieved in each direction is recorded, and combined with upper limb length to calculate the comprehensive scores for the left and right sides; the difference between the bilateral comprehensive scores is also calculated to evaluate upper limb dynamic balance ability and lateral control differences under closed-chain support conditions.
Grip Strength Test	K-Grip dynamometer (KINVENT) was used with athletes standing, the tested arm hanging beside the trunk and the elbow extended. Peak force in newtons was divided by body weight in newtons. Handle setting, trial count, contraction duration and rest require verification.
Weighted Pull-Up Test	Participants performed weighted pull-ups with a standardised pronated grip width. The maximum additional load permitting one valid repetition was recorded, and the additional-load-to-body-mass ratio was calculated as the measure of relative pulling capacity.

421 Table 2. Participant characteristics and data completeness

Variable	Valid n	Result/Completeness Rate
Included Samples	26	17 men, 9 women
Age (years)	26	17.85 ± 3.34
Years of training	26	4.31±1.74
Personal best (s)	26	6.59±2.06
OSTRC Total Score (points)	26	23.50 (0.00, 34.75)
UQYBT, I/Y/T, grip strength	26	100.0%
Weighted pull-up load relative to body mass	26	100.0%

422 Note: Age, years of training and best performance are expressed as mean ± standard deviation; the OSTRC total score is

423 expressed as the median (interquartile range).

424 Table 3. Upper limb functional measures and bilateral asymmetry

Measure	n	Median (interquartile range)
Average UQYBT Composite Score (%)	26	90.72 (87.21, 95.13)
Lower-side UQYBT composite score (%)	26	87.69 (83.03, 91.71)
Average relative strength (BW) for I/180	26	0.15 (0.12, 0.17)
Y/135 Average Relative Strength (BW)	26	0.17 (0.15, 0.19)

Measure	n	Median (interquartile range)
T/90 Average Relative Strength (BW)	26	0.24 (0.21, 0.27)
IYT Average Relative Strength (BW)	26	0.19 (0.16, 0.21)
Average peak grip strength relative to body mass (BW)	26	0.78 (0.71, 0.85)
Weighted pull-up load relative to body mass	26	0.87 (0.68, 1.01)
UQYBT composite bilateral difference (percentage points)	26	5.11 (2.71, 7.03)
I/180 asymmetry	26	0.14 (0.08, 0.19)
Y/135 asymmetry	26	0.11 (0.04, 0.18)
T/90 asymmetry	26	0.08 (0.04, 0.14)
IYT maximum asymmetry	26	0.18 (0.14, 0.21)
Peak grip strength asymmetry	26	0.07 (0.05, 0.12)

Note: BW denotes body weight. I/Y/T and grip force ratios are F/(m × 9.80665), with force in newtons and body mass m in kilograms. Additional pull-up load/body mass is kilograms/kilograms. Both ratios are dimensionless. Asymmetry = |L − R|/max(L, R), expressed as a fraction; UQYBT bilateral difference is in percentage points.

Table 4. Upper limb discomfort sites and questionnaire scores

Item	n	Results
Valid questionnaire samples	26	100.0%
Discomfort in either upper limb	17	65.4%
Discomfort in the shoulder/scapular region	9	34.6%
Discomfort in the fingers	9	34.6%
Elbow discomfort	1	3.8%
Wrist discomfort	1	3.8%
OSTRC total score (points)	26	23.50 (0.00, 34.75)
OSTRC ≥ 20 points	17	65.4%
Simultaneous discomfort in the shoulder/scapular region and fingers	2	7.7%
Simultaneous discomfort in the fingers and wrist	1	3.8%
Discomfort on the left side only	5	29.4% (of those experiencing discomfort)
Discomfort on the right side only	4	23.5% (of those experiencing discomfort)
Discomfort on both sides, more severe on the left	5	29.4% (of those experiencing discomfort)
Discomfort on both sides, more severe on the right	1	5.9% (of those experiencing discomfort)

Item	n	Results
Discomfort on both sides, of equal severity	2	11.8% (of those experiencing discomfort)
Any discomfort and OSTRC ≥ 20	17	65.4%

Note: Athletes may report discomfort in multiple areas simultaneously; therefore, the sum of the numbers for each area exceeds the number of athletes reporting discomfort in any single upper limb area. The side of discomfort refers to the overall side of the upper limb issue and cannot be attributed to a specific area among those reporting discomfort in multiple areas; the ‘any discomfort’ group and the ‘OSTRC ⩾ 20’ group comprise the same 17 individuals.

Table 5. Functional measures by presence of finger discomfort

Indicator	Finger discomfort group (n = 9)	Non-finger discomfort group (n=17)	δ	P	q
Composite score for the lower UQYBT side (%)	92.34 (87.54, 97.35)	85.37 (81.82, 90.07)	0.50	0.041	0.369
UQYBT average composite score (%)	94.73 (91.14, 98.01)	88.23 (86.75, 92.47)	0.52	0.036	0.369
IYT maximum asymmetry	0.14 (0.08, 0.18)	0.20 (0.17, 0.21)	-0.49	0.046	0.369
T/90 asymmetry	0.01 (0.01, 0.08)	0.11 (0.06, 0.16)	-0.57	0.020	0.369

Note: Data between groups are presented as medians (interquartile range); δ represents Cliff’s delta. None of the results reached $q < 0.05$ after multiple comparisons.

Table 6. Correlations between completion time and upper limb function

Indicator	n	ρ	P	q
Weighted pull-up load relative to body mass	26	-0.66	<0.001	0.005
Average relative strength on the IYT (BW)	26	-0.50	0.010	0.055
IYT Lower-Side Relative Strength (BW)	26	-0.51	0.010	0.055
I/180 Average Relative Strength (BW)	26	-0.42	0.033	0.105
Y/135 Average Relative Strength (BW)	26	-0.43	0.028	0.105
T/90 Average Relative Strength (BW)	26	-0.40	0.045	0.120
Average peak grip strength relative to body mass (BW)	26	-0.32	0.113	0.227
Peak grip strength on the weaker side relative to body mass (BW)	26	-0.34	0.095	0.216

Note: Best performance is defined as completion time (s); $\rho < 0$ indicates that the shorter the completion time, the higher the corresponding functional measure.

441 Table 7. Sex-adjusted correlations between completion time and upper limb function

Metric	n	ρ	P	q	Bootstrap 95% CI
YBT average composite score (%)	26	-0.19	0.383	0.438	-0.54 to 0.25
YBT lower-side composite score (%)	26	-0.13	0.552	0.552	-0.50 to 0.32
I/180 Average Relative Strength (BW)	26	-0.46	0.022	0.090	-0.73 to -0.07
Y/135 Average Relative Strength (BW)	26	-0.43	0.033	0.105	-0.68 to -0.08
T/90 Average Relative Strength (BW)	26	-0.36	0.078	0.177	-0.69 to 0.07
IYT Average Relative Strength (BW)	26	-0.48	0.014	0.077	-0.72 to -0.12
IYT Relative Strength on the Lower Side (BW)	26	-0.51	0.011	0.077	-0.73 to -0.14
Average peak grip strength relative to body mass (BW)	26	-0.18	0.359	0.438	-0.55 to 0.21
Peak grip strength on the weaker side relative to body mass (BW)	26	-0.20	0.305	0.438	-0.56 to 0.16
Weighted pull-up load relative to body mass	26	-0.55	0.008	0.077	-0.83 to -0.06
YBT Composite Bilateral Difference (percentage points)	26	-0.34	0.073	0.177	-0.63 to -0.02
I/180 asymmetry	26	0.34	0.091	0.182	-0.14 to 0.69
Y/135 asymmetry	26	0.25	0.230	0.409	-0.16 to 0.61
T/90 asymmetry	26	-0.23	0.258	0.413	-0.48 to 0.09
Maximum asymmetry of IYT	26	0.18	0.377	0.438	-0.26 to 0.52
Peak grip strength asymmetry	26	0.16	0.439	0.469	-0.26 to 0.53

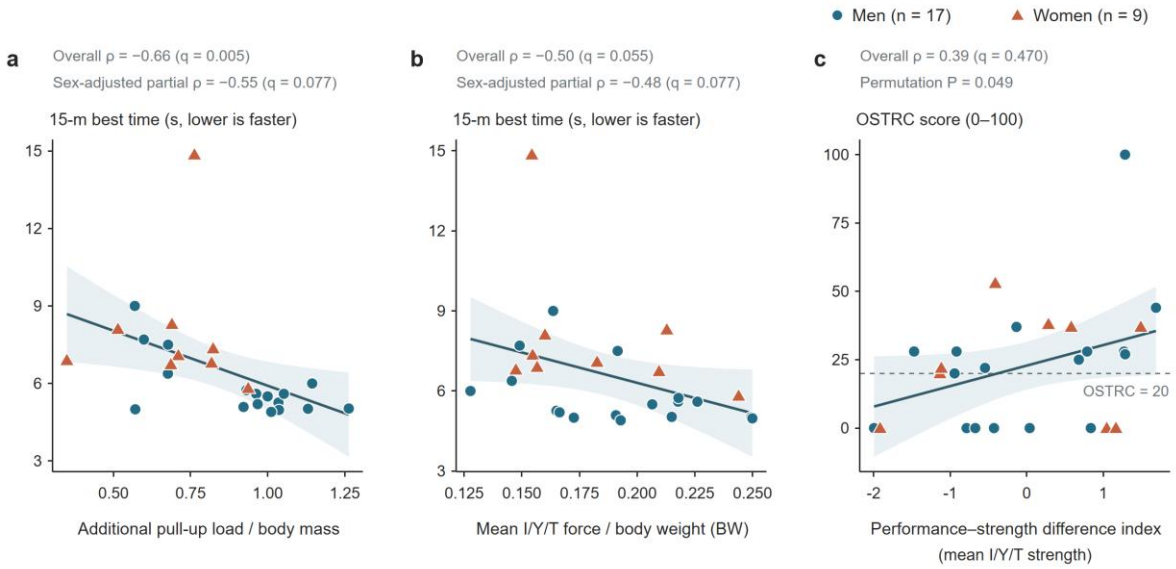
442 Note: Variables were rank-transformed and regressed on sex; correlations were calculated between residuals. P values were
443 obtained from 20,000 within-sex permutations and 95% confidence intervals from 10,000 sex-stratified bootstrap samples. q
444 values reflect Benjamini-Hochberg adjustment across 16 measures. Confidence intervals are unadjusted for multiplicity.
445 Values are reproduced from Supplementary Table S4.

446 Table 8. Correlations between bilateral asymmetry and symptom burden

Asymmetry Indicators	n	ρ	P	q
UQYBT Composite Bilateral Difference	26	0.06	0.777	0.777
I/180 Asymmetry	26	-0.13	0.513	0.733
Y/135 asymmetry	26	-0.17	0.395	0.733
T/90 asymmetry	26	-0.36	0.074	0.330
IYT maximum asymmetry	26	-0.32	0.110	0.330
Peak grip strength asymmetry	26	0.10	0.610	0.733

447

448 Fig. 1. Speed climbing performance, upper limb function and musculoskeletal discomfort



449

450 Each point represents one athlete (n=26); male and female observations are distinguished by shape and
451 colour. Solid lines and shaded bands show overall linear trends and 95% confidence intervals for
452 visualisation purposes only. Overall and sex-adjusted rank-based estimates are reported in the panels; sex-
453 stratified estimates are provided in the Results and Additional file 1, Table S6.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- BMC1027.docx