



Reliability and Measurement Error of a Climbing-Specific Upper Extremity Testing Battery for Sports Rehabilitation Monitoring

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Abstract

Background: Climbers place high mechanical demands on the fingers, wrist, elbow and shoulder. Rehabilitation and return-to-climbing decisions require objective tests that are reliable and clinically interpretable.

Objective: To establish the inter-tester reliability, test-retest reliability and measurement properties of a climbing-specific upper extremity testing battery for clinical monitoring.

Methods: Thirty recreational boulderers completed a three-session repeated-measures study. The battery assessed finger and shoulder pulling strength and endurance using a portable load-cell system. Reliability was assessed using ICC, SEM, MDC95, CV% and Bland-Altman limits of agreement.

Results: Finger and shoulder strength tests demonstrated excellent reliability. Endurance outcomes were more variable. Mean work force was the most stable endurance-derived outcome, while time to failure, repetitions to failure, AUC and fatigue index showed greater variability.

Conclusion: Climbing-specific finger and shoulder strength tests appear suitable for repeated clinical monitoring in recreational climbers. Endurance testing has clinical value but requires outcome-specific interpretation

Background

Climbing is an upper-limb dominant sport with high mechanical loads through the fingers, wrist, elbow and shoulder. These demands contribute to both acute and overuse injuries.

Return-to-climbing decisions are often based on symptoms, clinical judgement and progressive exposure. However, clinicians need field-based tests with known measurement error to decide whether a change in strength or endurance is likely to represent true change rather than normal testing variation.

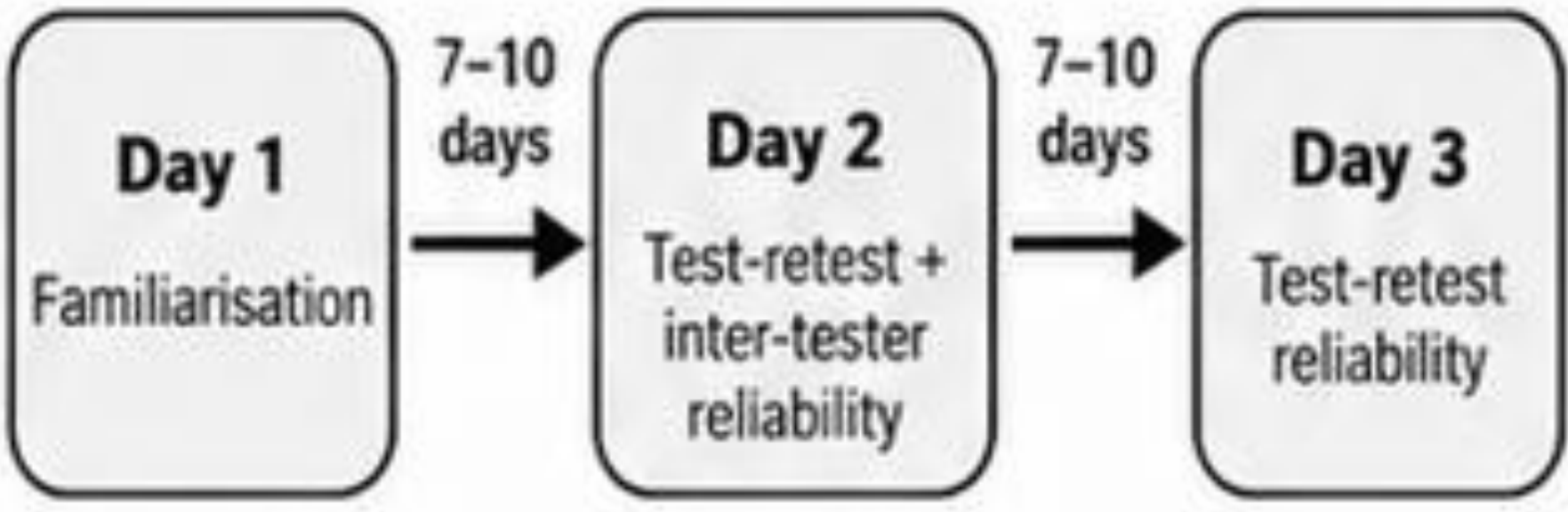
Aim

To establish the test-retest reliability, inter-tester reliability and measurement error of a climbing-specific upper extremity testing battery for sports rehabilitation monitoring.

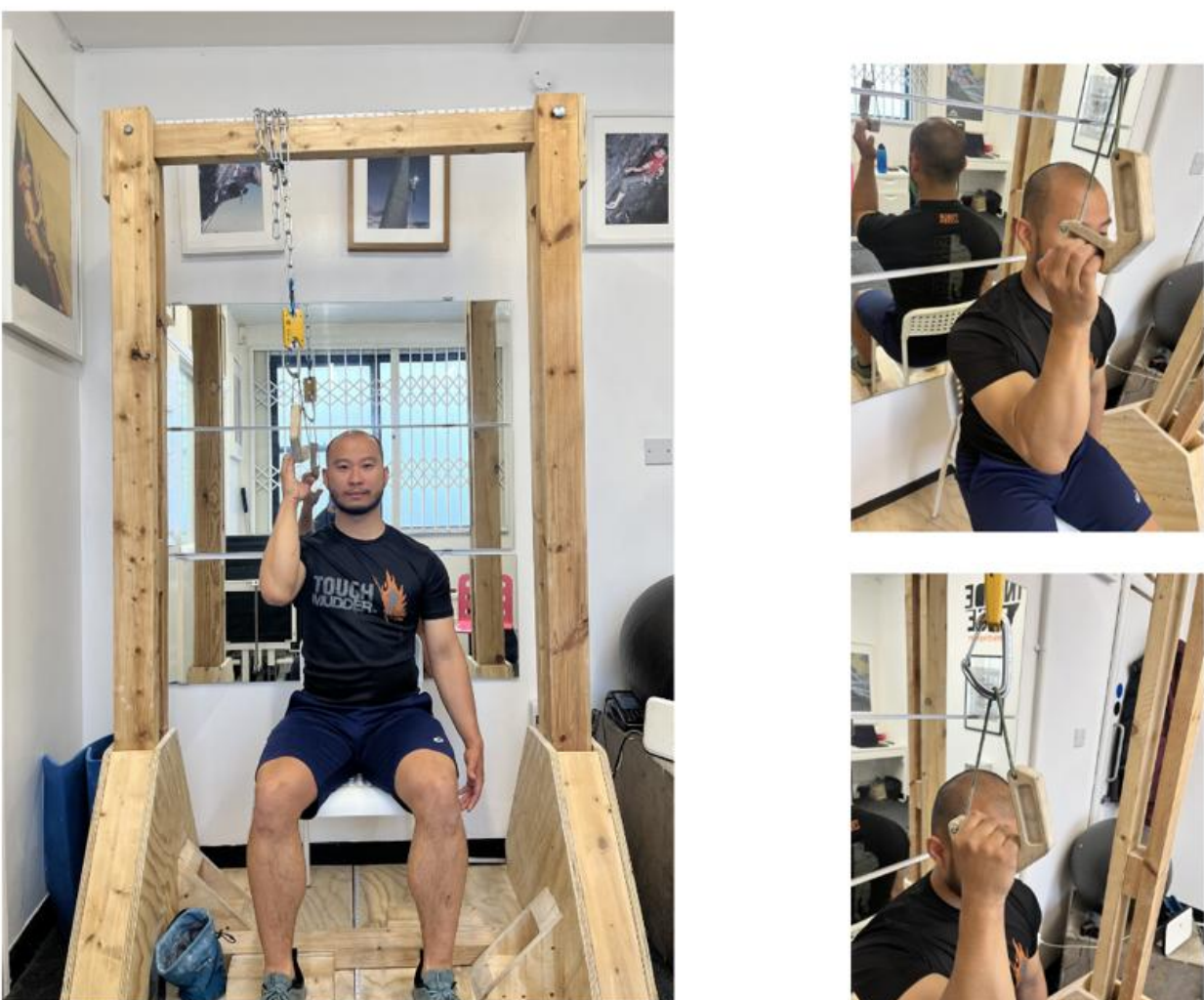
Participants

Number (n)	30 recreational climbers
Sex	23 male, 7 female
Age (years)	27.87 ± 7.14
Climbing level (Boulder grade)	V1-V9
Grade conversion	Grades converted to IRCRA (International Rock-Climbing Research Association) scale

Study Design



Testing Battery



- Finger pull strength:** Maximal isometric voluntary contraction using a fixed climbing edge.
- Shoulder pull strength:** Maximal isometric pulling using a wooden rung.
- Finger endurance: Repeated 7- second work cycles and 3 second rest cycles.
- Shoulder endurance:** Repeated 7- second work cycles and 3 second rest cycles.

Methods

- Portable Tindeq load- cell system used for all tests
- Fixed seated testing position to standardised posture and reduce variability
- Strength outcomes = peak force (Kg)
- Endurance outcomes = time to failure , repetitions to failure , mean work force , area under the curve(AUC) and fatigue index

Reliability Statistics

Statistic	Practical interpretation
ICC (Intraclass correlation coefficient)	Ranks people consistently (across repeated tests or testers)
SEM (Standard error of measurement)	Typical measurement error in kg
MDC95 (Minimal detectable change at 95% confidence)	Minimal change needed to be confident that a real change has occurred beyond measurement error
CV% (Coefficient of variation)	Error relative to force output (expressed as a percentage)

Main Results

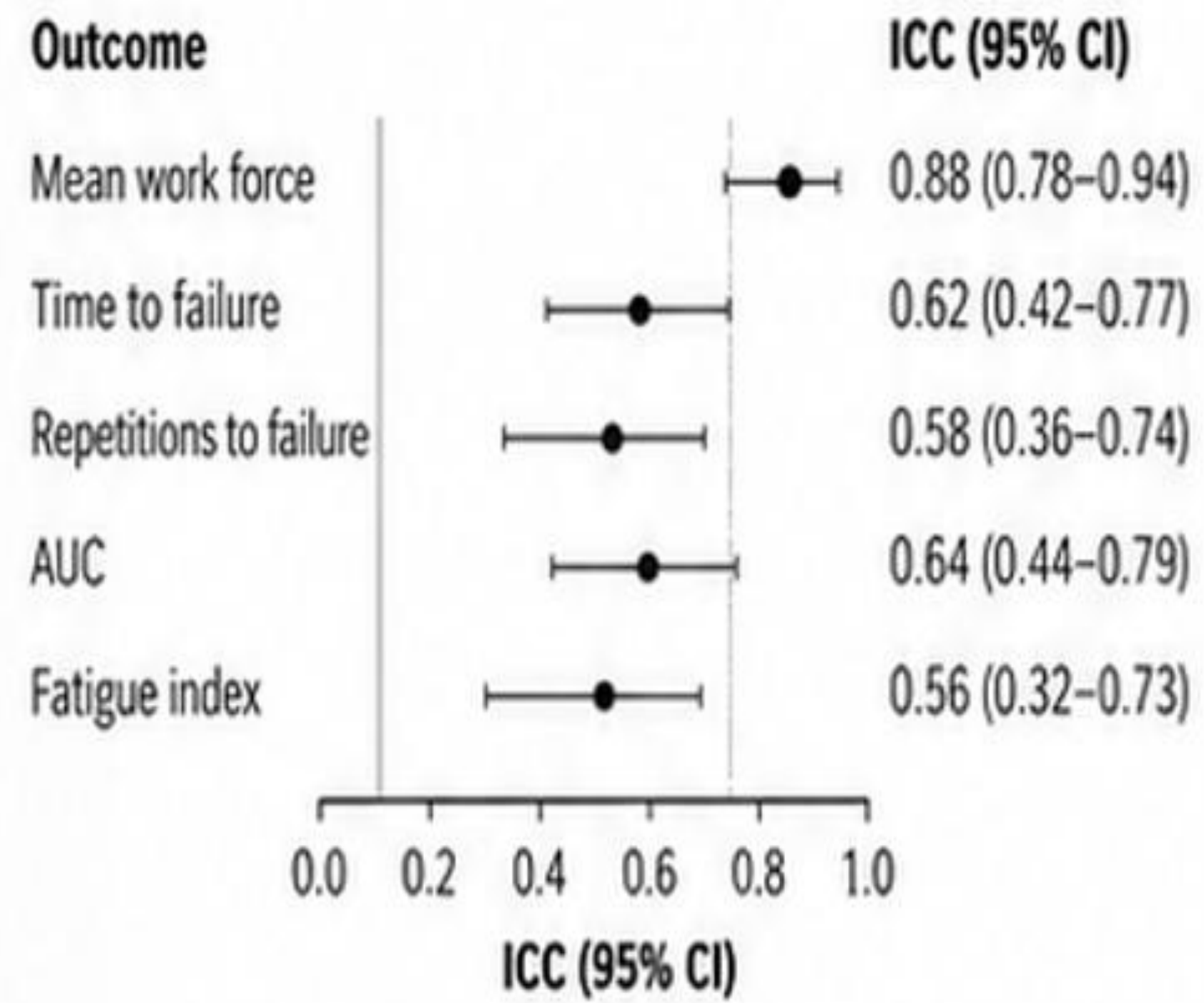
Strength test reliability (test-retest)

Test	ICC (95% CI)	MDC95 (kg)	CV%
Finger pull strength	0.98 (0.96–0.99)	4.8	2.5
Shoulder pull strength	0.96 (0.93–0.98)	6.7	4.2

Inter-tester reliability (strength tests)

Test	ICC (95% CI)
Finger pull strength	0.97 (0.94–0.99)
Shoulder pull strength	0.96 (0.92–0.98)

Endurance outcome reliability (test-retest)



- Strength tests were highly reliable (ICC= 0.96-0.98) with low measurement error (MDC 95 4.8-6.7 kg , CV % 2.5-4.2 %).
- Inter-tester ICCs for strength tests were 0.96-0.97.
- Mean work force was the most stable endurance outcome, while time to failure, repetitions to failure, AUC and fatigue index showed greater variability.

Clinical Interpretation

- Strength testing is the more clinically robust part of the battery.
- Use MDC95 to judge whether a change in performance is real
- Use the same tester where possible to reduce variability.
- Interpret endurance outcomes (time to failure . Repetitions to failure, ACU , fatigue index) cautiously due to greater measure error

Clinical Interpretation

This study supports the use of a climbing-specific upper extremity testing battery for sports rehabilitation monitoring. Finger and shoulder strength tests demonstrated excellent reliability and low measurement error. Mean work force was the most stable endurance outcome. Time to failure, repetitions to failure, AUC and fatigue index showed greater variability and should not be interpreted in isolation.

Further work is required to establish responsiveness and clinical utility in injured climbers.

Acknowledgements

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