Reliability, sensitivity, and minimal detectable change of a new specific climbing test for assessing asymmetry in reach technique

ular, Dražen; Dhahbi, Wissem; Kolak, Ivo; Dello Iacono, Antonio; Bešlija, Tea; Laffaye, Guillaume; Padulo, Johnny

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Reliability, sensitivity and minimal detectable change of a new specific climbing test for assessing asymmetry in reach technique.
Abstract:
The aims of this study were to establish inter-trial and inter-session reliability, sensitivity and minimal detectable change of a new climbing test specifically for assessing asymmetry in reach technique (TEST). Twenty-four young climbers (16 males and 8 females) participated in this study. The protocol consisted of performing, in counter-balanced random order, 3 tests; TEST, maximum handgrip force and squat on the bench, in two sessions (with three trials for each session). TEST performance was expressed as: TEST performance for left hand (TESTL), TEST performance for right hand (TESTR) and absolute symmetry index (ASI). For inter-trial and inter-session reliability assessment, TESTL and TESTR showed excellent reliability (Intra-class Correlation Coefficient – ICCs [3,1] ranged: 0.96-1.00; standard error of measurement – SEM% ranged: 0.07-1.23 and coefficient of variation – CV%: 1.28-2.53). In addition, SEMs were smaller than the smallest worthwhile change (SWC) values (SWC% = 1.07 and 0.99 for TESTL and TESTR, respectively), and also the minimal detectable change (MDC95) for both sides were small (<4.36 cm). An exception was ASI, which showed low absolute reliability and marginal sensitivity (SEM % = 15.13 > SWC% = 8.40 and CV% = 41.98). Pairwise test comparisons revealed no difference between sides. Considering the high reliability and the satisfactory sensitivity, TEST can be used to define individual asymmetry in the performance of the reach technique to the left or the right body side in climbers. However, interpreting data using the ASI index requires caution, as it had poor absolute reliability and marginal sensitivity.

Keywords: Kinesiology, performance, testing, prediction, motor control.
INTRODUCTION

Sport climbing is a highly demanding athletic activity (34) which requires certain morphological characteristics (11) and a high level of mental control (i.e., control of thoughts and emotions, and maintaining a mood in accordance with the goals) (5). A successful climber must also possess technical skills and a high level of physical fitness, such as handgrip and finger grip strength (6, 11). Shahram et al. (33) found that movements in sport climbing exert abundant pressure on the musculoskeletal system of the upper limbs, as a large percentage of body weight is usually held by one hand, or one or a few fingers, during a climb action. Climbing also requires the skill to be efficient when grabbing a handhold or standing on a foothold at different angles, positions and postures. By observing the technique performed by a climber athlete (22), the variability of the technique is a discriminative criterion for differentiating the climbers’ different level of expertise. In fact, the variability of the climbing technique is detected within and between subjects (10).

Bilateral symmetry (12) denotes symmetry of the left and the right side of the body around the sagittal plane (4). There is proof that during the performance of bilateral movements (of either arms or legs), one side of the body is activated more in overcoming load, in comparison to the other side of the body – mostly targeting stabilization demands (25). Furthermore, during bilateral movements, a so-called bilateral deficit (i.e., the difference in the summed force between contracting muscles alone and contracting contralateral homologous muscles in combination (30) occurs. In addition, bilateral deficit is characterized by a decrease in maximum voluntary contraction (MVC) force during bilateral activation of homologous muscles, compared with the sum of the forces produced during unilateral MVC of the muscles (29).

Natural ambidexters (i.e., perfect symmetry between both sides) are rare (1). Furthermore, it is known that the asymmetry of the body can be significantly reduced by training both sides of
As such, optimal symmetry training methods may improve metabolic clearance, isometric strength and endurance performance (a major determinant of sport rock climbing performance (18). The fact that the climbers are capable of developing motor skills on the non-dominant side of their body may potentially improve climbing performance (7).

Upper-limb movement asymmetries and leg force production asymmetries are thought to be detrimental for the climbers’ performance, and may cause risk of injury. By using coefficients of asymmetry (the mean of the relative differences between the right and left side divided by 0.5, multiplied by the sum of right and left side (32)), a coach may determine side dominance and introduce program efficient training plans to address right-left discrepancies (35). Previous studies in athletics have focused on asymmetries in tennis players (20), by investigating morphological asymmetry of these athletes. Similarly, body asymmetry was assessed in other studies conducted on elite soccer players (24, 35). An investigation of soccer players (35) determined a positive effect of training in which technical soccer motor skills were practiced by both feet. Čular et al. (7) investigated the effect of the dominant and non-dominant side of the body on taekwondo performance. The obtained results support the phenomenon that the non-dominant side is the place for athletes’ improvement in most sports activities, and its identification is of interest to coaches. To the best of our knowledge, this paradigm has never been investigated in climbing.

In this aspect, technological advances and practical uses of devices enabling the assessment of athletes’ asymmetry represent an interesting area of research. The availability of valid and reliable specific tests assessing the performance, technique and asymmetry index of climbers, may help coaches and practitioners in structuring individual training plans more efficiently. Therefore, the goal of the present study was to validate a specific test for climbers (e.g., a specific climbing test for assessing asymmetry in reach technique – TEST) able to provide
indices of performance and asymmetry during reach techniques by the left and the right sides of the body.

METHODS

Experimental Approach to the Problem

A cohort-based, randomized, repeated measures study design was used. The experimental protocol consisted of performing the specific climbing test for assessing the asymmetry in reach technique (TEST) three times. One week before baseline testing, a session was carried out to familiarize the participants with the measurement protocol. Both sessions of baseline testing were dedicated to the assessment tests: TEST, maximum handgrip force for both hands and squat on the bench for both legs.

Subjects

Twenty-four climbers (16 male and 8 female), from the sport climbing club Citius-Altius-Fortius from Split, voluntarily participated in this study. All anthropometric data (age, body height, body mass, sitting height, biacromial range, body mass index, total percentage of body fat, total muscle mass, torso percentage body fat and torso muscle mass) can be found in Table 1. All participants had a right dominant hand (as the one used for writing) (31). The inclusion criteria for participation in this study were: a minimum weekly training frequency of 3 sessions, or a total time of 180 min of climbing activities per week; more than 1 year climbing training experience, free from any injury or pain that would have prevented maximal effort during testing. All subjects gave their written informed consent to participate in the study after receiving a thorough explanation of the study’s protocol. The protocol conformed to internationally accepted policy statements regarding the use of human participants in accordance with the Declaration of Helsinki, and was approved by the University’s Ethics Committee.
Procedures

The protocol consisted of the performance of the 3 tests in counter-balanced random order, with 3 trials for each test. The recovery time was 5 min between trials, and 10 min between tests. Test and retest protocols were identical. The 2 best attempts out of the 3 trials for the first baseline session were kept for analysis of the inter-trial reliability of TEST. To examine the intersession reliability and sensitivity of TEST, the best scores of testing sessions 1 and 2 were compared.

Before starting the tests, the participants performed ~15 minutes of warm-up, which included circumduction and flexion/extension of the upper limbs with self-selected intensity, and dynamic stretching (pectoralis, trapezius, arm flexor and extensor, flexors and extensors of the hand/fingers). After the warm-up, the participants recovered for ~5 minutes and then began the tests. Test data were collected at approximately the same time of day (morning) in both sessions (between: 09:00 and 11:00 a.m.) in order to eliminate any influence of circadian variations on performance (16). Participants were asked to follow their normal diet, eat a light meal at least 3 hours before each session, sleep normally and cease any strenuous activity during the 24 hours before the test. The experimenter provided strong verbal encouragement during the tests to obtain maximum efforts from the participants. To ensure the same testing conditions, all participants were tested by the same raters. The test was performed on a specially designed measuring board in an indoor rock climbing center (measurements were taken every 30 min during the experiment): temperature 20±0.5 °C and humidity 50±10%, monitored by a digital environmental station (VaisalaOyj, Helsinki, Finland) during the test and the retest sessions.

Specific climbing test for assessing asymmetry in reach technique (TEST):
**Initial position** (Figure 1): On the measurer's mark, the subject stood in an initial position by placing the right hand on the first handhold, so that the middle finger was placed in the middle of the hold. The subject then placed the left hand on the left edge of the handhold, right next to the right hand, with the right foot placed with its inner edge on the initial foothold. The subject was ready to perform the test when they lifted their left foot from the surface and placed it on the foothold.

**Test performance:** On the measurer’s mark, the subject started performing the test by moving their body to the left so that the left knee, hip and shoulder moved to the left by transferring the centre of gravity to the left leg. The subject then moved the right foot from the initial foothold, and the inner edge of the climbing shoe was placed on the part of the rock without the foothold (so-called “friction”), so that the foot was facing the opposite direction from the hand reach. Then the climber let go of the handhold held by his/her left hand and reached with his/her hand on the measuring tape to the maximum distance.

**Final position** (Figure 2): In the final position, the climber’s centre of gravity was transferred to the left side in relation to the initial position, and the subject rested on the left foot and gripped with the right hand. The left hand was placed on the measuring tape and was held still for a minimum of 3 seconds before the result of the maximum reach was read. The right foot was placed on the rock with the inner edge of the climbing shoe facing opposite of the left hand.

**** Insert Figure 1, 2 and 3 about here ****

Three performance indices were calculated from TEST: (i) TESTL: specific climbing test of reach for the left hand (cm), (ii) TESTR: specific climbing test of reach for the right hand (cm) and (iii) ASI: absolute symmetry index (%). ASI was used to evaluate symmetry between the left and right sides (21):
Equation (1): Absolute symmetry index (ASI%) = $\frac{|\text{TESTR}-\text{TESTL}|}{0.5 \times (\text{TESTR}+\text{TESTL})} \times 100$

It should be noted that the lower the levels of ASI indicated more symmetrical sides.

**Equipment and installation:** The experiment was conducted on an artificial rock which had been specially constructed for the purposes of the experiment. The rock was placed at a 90° angle in relation to the horizontal surface, on a 262 × 262 cm square with marked positions of the handholds, footholds and measuring tapes. The marked square was horizontal in relation to the surface, with the lower side at a 30-cm distance from the surface (Figure 3.1). The main handhold was placed at the point where the diagonals of the square intersect (Figure 3.2), and its upper surface was parallel to the board surface and had a dent which marked the position of the middle finger of the gripping hand during test performance. Measuring tapes were placed upwards along the diagonals and their starting point (zero) was in the hole for fastening the handhold. The hole on the handhold was 12 mm in diameter. At the lower part of both diagonals, at a 106 cm distance from the hole for the main (A) handhold, footholds with limiters (Figure 3.3 and 3.5) were placed so that the limiter was vertical to the surface (Figure 3.3 and 3.5). From the position of fixation of the main handhold, a vertical line was drawn to the surface and a hole was drilled at a 125 cm distance from where initial foothold of regular circular shape was placed (Figure 3.4). The surface for the test performance was secured by a mat 5 cm thick and 3×1 m long. The handholds and footholds were specially designed for the purposes of this experiment by the “Vulkan” hold manufacturer; the name of the series is “A set of handholds and footholds for the reach test”.

**Hand grip strength (right hand and left hand):**

This test was performed according to the hand grip strength protocol, described by España-Romero et al. (17). Both hands (i.e., left and right) were evaluated. The hand to be tested
first was randomly chosen. The Takei Hand Grip Dynamometer (Takei A5401 Digital Hand Grip
Dynamometer; error 0.001 gr) is a digital tool with an adjustable grip span.

**Squat on the bench (right leg and left leg):**

This test was performed according the protocol described by Čular et al. (8). The test was completed when the subject could not stand up correctly anymore and remained sitting on the chair. The test result was expressed as the number of correct repetitions of standing up and sitting down on the chair. The subjects performed a maximum number of repetitions, and the test was not time-limited. The procedures were repeated on the opposite leg.

**Statistical Analysis**

Data analyses were performed using SPSS version 23.0 for Windows. Means and standard deviations (SD) were calculated after verifying the normality of distributions using Kolmogorov-Smirnov statistics. Dependent $t$-tests were used to evaluate the equality of means for left and right sides climbers’ TEST, maximum handgrip force and squat on the bench tests, and it was also used to investigate systematic bias. Estimates of effect size (Cohen’s $d$), mean differences and 95% confidence intervals (CIs) protected against type 2 errors. The relative reliability of TESTL, TESTR and ASI was determined by calculating the Intra-class Correlation Coefficient model 3,1 ($ICC_{[3,1]}$), and the absolute reliability was expressed in terms of SEM and coefficients of variation (CV). The sensitivity of the test was assessed by comparing the smallest worthwhile change (SWC) and SEM, using the thresholds proposed by Liow and Hopkins (23). Minimal detectable change at 95% confidence interval ($MDC_{95}$) was also calculated for TESTL, TESTR and ASI indices. Heteroscedasticity was examined. Significance for all the statistical tests was accepted at $p<0.05$.

**RESULTS**
**Inter-trial reliability of the specific climbing test**

The pairwise analysis of TESTL, TESTR and ASI indices revealed no significant difference in-between trials ($p: 0.67-0.95$; $d: 0.01-0.09$ [trivial]). Moreover, performance for both sides (i.e. TESTL and TESTR) and ASI showed a high degree of ICC between trials ($ICCs_{[3,1]}$ was 1.00, 0.99 and 0.89, respectively). TESTL and TESTR showed an excellent absolute reliability (SEM%: 0.07-0.25; CV: 1.31-2.53). **Contrarily** ASI, that showed low absolute reliability (SEM % = 11.57 and CV % = 35.20). **In addition**, there was no heteroscedasticity in the raw data ($r$: -0.21-0.29; $p$: 0.17-0.33).

**** Insert Table 2 about here ****

**Intersession reliability and sensitivity of the specific climbing test.**

TESTL and TESTR showed an excellent reliability ($ICCs_{[3,1]}$: 0.95-0.96 and SEM%: 2.85-3.40). On the other hand, TEST showed a satisfactory sensitivity, Hence SEMs values were approximately equal to SWC values (SWC% = 1.07 and 0.99 for TESTL and TESTR respectively). **In addition**, the MDC$_{95}$ for both sides were small (<4.36 cm) (Table 3). In accordance with inter-trial results, ASI showed poor absolute reliability (SEM % = 15.13 and CV% = 41.98) and marginal sensitivity (SEM %= 15.13 > SWC% = 8.40 and MDC$_{95}$ % = 41.96). Heteroscedasticity coefficients for TESTL, TESTR and ASI were all small and non-significant ($r=0.18 \ [p=0.40], r=0.11 \ [p=0.61]$ and $r=0.19 \ [p=0.39]$, respectively).

**** Insert Table 3 about here ****

**Comparison of the specific climbing test and strength tests between right and left sides**

A pairwise sample $t$-test revealed no difference between sides (Table 4) for TEST ($p=0.802; \ d=0.05$ [trivial]), maximal handgrip strength ($p=0.351; \ d=0.20$ [small]) and squat on the bench ($p=0.672; \ d=0.11$ [trivial]). The corresponding stepwise regression equations are shown in Table 4.
DISCUSSION

The aims of this study were to establish the inter-trial and intersession reliability, sensitivity and minimal detectable change of a new specific climbing test for assessing asymmetry in reach technique (TEST). To the authors’ knowledge, this is the first reported evaluation of TEST. The main findings of this study were that TEST is highly reliable and sensitive for assessing symmetry in reach technique. However, the absolute symmetry index (ASI) had poor absolute reliability and marginal sensitivity.

By providing reliable and valid assessments, climbing coaches can advance training programs while limiting injury prevalence. The variability between trials may be considered to be intrinsic variation, as it provides a basic indication of the variation independent from other sources of error (13). The inter-trial variability is free of methodological errors, cannot be reduced, and thereby serves as an appropriate baseline for comparisons (14, 26). The inter-trial reliability of TEST performance is important to ensure that observed differences between testing trials are not due to systematic bias, such as a learning effect, fatigue or random error due to possible biological or mechanical variations. The inter-trial variability is usually caused by the emotional state of subjects between the trials, and by their level of experience with the measuring system (26). On the other hand, between-day reliability represents an important aspect of performance testing. Poor reliability might result in different scores for the examinee across the two test administrations, which may be conducted with erroneous data interpretation (9).

The Intra-class Correlation Coefficient (ICC) can be used to assess relative reliability, which indicates the maintenance of group position (rank order) on the tests across the two measures (9). With ICCs scores ranging from 0.87 [good] to 1.00 [excellent], TEST (e.g., TESTL, TESTR and ASI) demonstrated a high inter-trial and intersession relative reliability. A
weaknesses of ICC is that it is affected by the heterogeneity of the sample (37). Therefore, an
examination of the SEM, which provides an absolute index of reliability, is needed (37) to
confirm the ICC’s results. The SEM is not affected by inter-subject variability (37), and provides
an estimate of measurement error. In addition, if data are homoscedastic, which is the case in all
parameters of this study ($r$: -0.21 - 0.29; $p$: 0.33 - 0.61), SEM analysis may be more useful for
establishing absolute reliability (2). With heteroscedastic data, CV analysis is recommended (2).
SEM% values lower than 5% may interpreted as good absolute reliability (28). Using the same
idea, inter-trial and intersession SEMs% of this investigation ranged from 0.07% to 1.23 % for
both TESTL and TESTR performances. The CVs of TESTL and TESTR ranged from 1.31-
5.37% and 2.53-4.96%, respectively, which can be considered good (<10%) (2), whereas ASI had
a poor absolute reliability (SEMs% <5% and CVs% <10%).

We also calculated the likelihood that differences in TEST outcomes were substantial
(i.e., SWC larger than the SEM). As for TESTL and TESTR, SEMs were approximately equal to
the SWCs values (Table 3), indicating that the measurements have a “satisfactory” potential to
detect real changes in the performance output of the body. In contrast, the SWC for the ASI
(8.40%) was smaller than the parallel SEM (15.13%) (Table 3). The lack of contralateral
climbing experience is a factor that may have influenced the results. Assessment of an apparent
change in performance depends on the magnitude of the change in score relative to error size
(MDC$_{95}$) (19). The MDC$_{95}$ values for TESTL, TESTR and ASI were 4.36 cm, 3.67 cm and
1.94%, respectively. Thus, a change in TESTL, TESTR and ASI scores exceeding 4.36 cm, 3.67
cm and 1.94%, respectively, can be accepted as a true response (2), and one can be 95%
confident that a true change has occurred beyond measurement error in climbers.

Pairwise comparisons revealed no difference between left and right sides for TEST
($p$>0.05; $d$: [trivial]). Similar results were achieved in the maximal handgrip strength test
(\(p=0.351; \, d=0.20\) [small]) and squat on the bench test (\(p=0.672; \, d=0.11\) [trivial]). This is likely associated to the specific functional demands in terms of climbing techniques that involve four supports (i.e., the hands and legs) (15). In view of the maximal handgrip strength, and consequently the forearm muscles’ strength, has been described as a good indicator of climbing performance (3, 15, 36). Conjointly, strength and power of the lower limbs were a physical requirement of paramount importance for overall climbing performance (27). Hence, this consistency between the results of the three tests (i.e., TEST, maximal handgrip strength and squat on the bench) confirms the sensitivity of TEST to detect the difference in performance between climbers’ sides.

The results confirm that the newly constructed specific measuring instrument (i.e., TEST) has good metric characteristics and can be used to assess the level of asymmetry between left and right reaching techniques. In summary, the use of TEST on both body sides, due to its highly reliable and satisfactory sensitivity, can be confirmed for defining individual asymmetry in the performance of the reach technique to the left or the right body side on a sample of athletes involved in sport climbing. However, interpreting data using the ASI index requires caution because it had poor absolute reliability and marginal sensitivity. Finally, the results of this study open up the possibility for further research in the area of asymmetry in sport climbing, and to arrive at more precise and quality conclusions, future studies should involve a larger number of subjects of different ages.

**PRACTICAL APPLICATIONS**

Due to its simplicity in terms of performance, the small amount of equipment required to be performed, the cost-effective field and the possibility of simultaneous testing of multiple subjects in a relatively short time period, this test can be a popular field-specific test for climbers. Additionally, based on its high reliability and satisfactory sensitivity, this test is suitable for
application in monitoring, evaluating and programming the transformation processes of symmetry in reach skills for climbers.

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**FIGURE LEGENDS:**

**Figure 1:** Initial position to the left.

**Figure 2:** Final position to the left.

**Figure 3:** Construction of the «board» for performance testing.

(A) “Board without holds”, (B) “A main handhold”, (C) A1 “left foothold”; (D) B “main foothold”; (E) A2 “Right foothold”

**TABLES LEGENDS:**

**Table 1.** Descriptive statistical indicators of morphological variables (N=24)

**Table 2.** Intertrial relative and absolute reliability indices of the specific climbing test
Table 3. Intersession relative and absolute reliability indices and MDC\textsubscript{95} of the specific climbing test

Table 4. Comparison of mean values between right and left sides