Description and Intrarater Test–Retest Reliability of a Reverse-Action Method to Assess Ankle Evertor Muscle Performance: The I-to-V Test

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ABSTRACT

Purpose: Reverse action (RA) of the ankle evertor muscle is when the proximal attachment moves toward the distal attachment, moving the lower leg in the frontal plane when the foot and ankle are fixed on the ground and inducing ankle eversion. The purpose of this study was to describe an RA method for measuring ankle evertor muscle performance. **Method:** Eighteen healthy individuals were recruited for this study. To assess the RA of their ankle evertors, the participants sat with their knees together and their feet firmly planted on the floor, then spread their knees as far apart as possible. A tester used a measuring tape to measure the distance (in cm) between the medial tibial tuberosity of the tested side and that of the non-tested side. In the end range position of the RA, ankle evertor electromyographic activity was recorded simultaneously. The intra-class correlation coefficient (ICC) and standard error of measurement (SEM) were calculated to establish the intrarater test–retest reliability. The correlation between each performance value and muscle activity was assessed using a linear correlation model. **Results:** The proposed method of assessing RA performance was highly reliable (ICC = 0.95) and had a low SEM (1.63 cm); in addition, the performance value showed a strong positive correlation with ankle evertor muscle activity ($p = 0.90$; 95% CI: 0.79, 0.95; $p = 0.01$). **Conclusions:** The proposed RA method of assessing the ankle evertor muscles can be used as a simple, reliable, economical performance test. It can also be used as an alternate method of testing the peroneal muscles rather than selectively measuring ankle evertor performance because hip external rotation occurs when performing RA.

Key Words: ankle; muscle performance; peroneus longus; reproducibility of results.

RÉSUMÉ

Objectif : lors de l'inversion du muscle éverseur de la cheville, l'attache proximale se déplace vers l'attache distale et, si le pied est posé à plat sur le sol, la jambe inférieure se place dans le plan frontal et on observe une éversion de la cheville. La présente étude vise à décrire une méthode d'inversion pour mesurer le rendement du muscle éverseur de la cheville. **Méthodologie :** les chercheurs ont recruté 18 personnes en bonne santé. Pour évaluer l'inversion des éverseurs de la cheville, les participants se sont assis, ont rapproché les genoux et posé les pieds à plat sur le sol, puis ont écarté les jambes le plus largement possible. À l'aide d'un ruban à mesurer, un évaluateur a mesuré la distance, en centimètres, entre la tubérosité tibiale médiane du côté testé et celle du côté non testé. En inversion maximale, l'activité électromyographique des éverseurs de la cheville était enregistrée simultanément. Les chercheurs ont calculé le coefficient de corrélation interne (CCI) et l'écart-type de la mesure (ÉTm) pour établir la fiabilité intraévaluateur du test-retest. Ils ont évalué la corrélation entre chaque valeur de rendement et l'activité musculaire au moyen du modèle de corrélation linéaire. **Résultats :** la méthode proposée pour évaluer le rendement de l'inversion était très fiable (CCI = 0,95) et l'ÉTm était, faible (1,63 cm). De plus, la valeur de rendement a révélé une corrélation positive solide avec l'activité du muscle éverseur de la cheville ($p = 0,90$; intervalle de confiance à 95 % = 0,79, 0,95; $p = 0,01$). **Conclusion :** la méthode d'inversion proposée pour évaluer les muscles éverseurs de la cheville est un test de rendement simple, fiable et économique. Elle peut également être utilisée pour tester les muscles péroniers plutôt que pour mesurer sélectivement le rendement de l'éverseur de la cheville en raison de la rotation externe de la hanche pendant l'inversion.

Insufficient ankle muscle performance contributes to various conditions of the lower extremity.^{1–3} The ankle muscles, specifically the ankle evertors, not only provide ankle dynamic stability but also maintain proper alignment of the lower extremity in the frontal plane.¹ A meta-analysis showed that weakness of the ankle evertors is associated with ankle instability in people with functional ankle instability.⁴

Previous studies have evaluated the standard action (SA) of peroneus longus (PL) performance using motor-driven^{5,6} or handheld dynamometers.^{7,8} However, reverse action (RA) commonly occurs during functional activity when the foot is firmly on the ground, such as when standing, sitting, or walking.⁹ In RA, the proximal attachment of the PL muscle moves toward the distal attachment, moving the lower leg in the frontal plane when

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the foot and ankle are firmly on the ground. In SA, the opposite occurs.⁹ The SA of the peroneal muscles occurs before heel strike in the gait and prevents ankle sprain,¹⁰ and RA of the peroneal muscles occurs after heel strike and in the propulsion phase of gait.¹¹

In previous studies, a measuring tape has been used to assess performance. For example, in the Star Excursion Balance Test,^{12,13} eversion strength contributes to the posteromedial and posterolateral reach in individuals with chronic ankle instability.¹² Performance measurement methods using a measuring tape are easy-to-use outcome tools,¹⁴ and have the advantage of requiring little equipment.

Surface electromyography (EMG) has been used as an appropriate measure for comparing the contributions of the muscles during movement and exercise.^{15,16} The relationship between the force produced by the muscles and EMG activity during movement has long been documented, with reasonable success.¹⁷ Studies in which handheld dynamometers were used have suggested that a future study including EMG is needed to clarify the relationship between EMG activity and muscle strength.^{18,19}

The primary aim of our study was to describe a method of assessing the RA performance of the PL muscle by using a measuring tape. The secondary purpose was to estimate the intrarater test–retest reliability of the proposed method of RA performance of the PL muscle in healthy individuals. The activation level of the PL muscle was also quantified during the RA of the PL. Our hypothesis was that both the RA and the SA methods would demonstrate high test–retest reliability (intra-class correlation coefficient [ICC] [2.2] > 0.70). We also hypothesized that under the RA condition the performance value would show a positive correlation with PL muscle activity.

METHODS

Participants

We conducted a power analysis to estimate the sample size required for a reliability study using ICC. The parameters used for this sample size estimation were a significance level of 0.05, a power of 80%, a minimum acceptable reliability of 0.7, and a target reliability of 0.9. This method suggested that a sample size of 18 would be required. We recruited 18 healthy, young participants from a local university: 10 men, with a mean age of 24.6 (SD 2.8) years, height of 174.5 (SD 6.2) centimetres, and weight of 69.0 (SD 9.2) kilograms, and 8 women, with a mean age of 22.3 (SD 2.2) years, height of 161.5 (SD 3.3) centimetres, and weight of 57.8 (SD 3.8) kilograms.

Participants who met any of the following criteria were excluded: (1) a history of surgery on the lower extremity, (2) a history of acute or chronic ankle sprain,

(3) previous or present functional ankle instability, (4) previous or present discomfort during daily or physical activity, (5) any medical condition that could influence their ability to perform maximal force exertion, and (6) restricted active range of ankle eversion and hip external rotation. Before our study began, the principal investigator (KNP) explained all the procedures to the participants in detail. Informed consent was obtained according to guidelines established by the university's institutional review board.

Materials

Handheld dynamometer

A handheld dynamometer (model 01163; Lafayette Instrument Co., Lafayette, IN) was used to assess the SA performance of the PL muscle. The dynamometer was capable of measuring up to 136 kilograms with an accuracy of $\pm 1\%$, as reported by the manufacturer, and allowed recording of the peak force generated.²⁰

Metric measuring tape

A metric measuring tape with the ability to measure to 0.1 cm was used to assess the RA of the PL muscles.

Foot switch

A Model 500 DTS footswitch (Noraxon USA, Scottsdale, AZ) was used to verify whether the participants' ankle and foot were firmly on the ground when they performed the RA while sitting. Data were collected at 1000 Hertz. Two foot switches were attached: one under the mid-point of the plantar aspect of the heel and the other at the base of the first metatarsal. The foot switch at the base of the first metatarsal is the same point at which resistance was applied during the strength test of the PL muscle in a previous study.²¹ In that study, resistance was applied to the base of the first metatarsal toward 45 degrees medially to the longitudinal axis of the tibia to resist pronation with eversion because the PL muscle acts in both pronation and eversion.²¹ The trigger signals of the foot switches were identified visually in real time using myoRESEARCH 1.06 software (Noraxon USA, Scottsdale, AZ).

Surface EMG

Electromyographic activation of the PL under both the RA and the SA conditions was assessed. EMG data for the PL muscle were collected using a Noraxon TELEmyo system (Noraxon USA, Scottsdale, AZ) and analyzed using Noraxon myoRESEARCH 1.06 software. Surface electrode pairs with a sampling rate of 1000 Hertz were positioned 2 centimetres apart. Electrode attachment locations were cleaned by sanding them and applying rubbing alcohol to remove any dead skin. An electrode was attached approximately 4 centimetres distal to the fibula head along the longitudinal axis of the PL.²² A bandpass filter was used between 10 and 450 Hertz, then raw data were

processed into the root mean square (RMS) with a 50-microsecond window.

For normalization, data for the maximum voluntary isometric contraction (MVIC) were collected from the highest 1 second of EMG activity during the SA method; this represented 100% muscle activation. The average EMG activity during the middle 3 of 5 seconds for either the RA or the SA condition during the SA method was normalized to the mean amplitude of the highest 1 second of EMG activity.

Procedures

Only the dominant leg (defined as a participant's preferred leg for jumping and landing) was tested for range of motion (ROM) and performance measurements. The active ROM was measured first by Tester 1 to obtain baseline data. Then the participants were assigned randomly to the RA condition or the SA condition using the random-number function in Microsoft Excel. Before we took any measurements, the participants were asked to warm up by performing active ankle eversion maximally three times, holding each for 10 seconds.

To assess within-day intrarater reliability, measurements were performed by trained testers (Tester 2 for the RA measurements and Tester 3 for the SA measurements), both of whom are orthopaedic physical therapists with 8 years of experience. The RA and SA methods were performed on the same day but in separate rooms to reduce measurement bias. Both RA and SA measurements consisted of two data collection sessions; two consecutive measurements of 5 seconds each for both evorper performances were taken at both data collection sessions. A 1-minute rest period was allowed between consecutive measurements to allow the participants to recover. The mean of the two consecutive measurements was used for analysis because the mean value is more reliable than the maximum value.²³ The EMG data were recorded simultaneously with each RA and SA performance measurement.

Measuring ROM to obtain baseline data

The active ROM for ankle eversion and hip external rotation was measured to confirm that the participants had sufficient ROM in the RA condition. Resting ankle plantar flexion passive ROM was measured in the SA condition to apply the same degree of plantar flexion as in the RA condition. The active ROM of ankle eversion,²⁴ passive ROM of ankle plantar flexion in the resting position,²⁵ and active ROM of hip external rotation²⁶ were measured by Tester 1 bilaterally while participants were seated on a table with their foot unsupported. A universal goniometer with an arm length of 17 centimetres from axis to tip was used. An average of three trials for each ROM measurement was used for the data analysis. The ROM of the ankle eversion, resting ankle plantar flexion, and hip external rotation were sufficient to evaluate the

RA and SA performance in our study: 9.1 (SD 3.7) degrees, 25.6 (SD 5.8) degrees, and 38.4 (SD 8.0) degrees, respectively.

Assessing RA performance (proposed method)

To assess RA performance, we asked the participants to sit upright in a chair with their hips flexed to 90 degrees and feet on the floor, and then to place their knees and feet together. To provide conditions similar to the SA method, resting ankle plantar flexion—25.6 (SD 5.8) degrees—was positioned at the same angle as that obtained in the resting plantar flexion ROM test described earlier (see Figure 1a). To perform the RA for the PL muscle, the participants were asked to place one foot as firmly on the floor as possible, without moving it, while performing active hip external rotation. We requested hip external rotation because it induces movement of the tibia relative to the fixed foot, resulting in the RA of the ankle eversion. The greater the hip external rotation, the greater the need for ankle pronation with eversion to fix the foot; this represents the optimal action of the PL muscle as a multi-joint muscle.

Tester 2 instructed the participants to sit with both feet together, firmly planted on the floor, and then to spread their knees apart. The tester clarified these instructions as follows: "Imagine the uppercase letters *I* and *V*. In the starting position, your legs should form the letter *I*; then spread them apart to form the letter *V*." (These positions are shown in Figures 1b and 1c.) When the EMG data were obtained during the isometric maximal hold for the letter *V*, Tester 2 measured the movement of the lower leg by using the measuring tape to measure the distance between the proximal medial tibia tuberosity of the tester's side and the opposite side. Tester 2 also gave each participant standardised verbal encouragement with every effort.

If the foot switches at the base of the first metatarsal were turned off during the RA, it indicated that the participant's feet were not firmly on the floor, and the participant was asked to try again. Toe extension at the metatarsal phalangeal joint was permitted when the participants tried to push the floor using the base of the first metatarsal, as in a previous study.²¹ To normalize the data for the RA method, the normalized performance value was calculated as a percentage as follows: [(non-normalized value in cm / tibia length in cm) × 100]. Tibia length represents the distance between the most proximal point of the medial condyle of the tibia and the most distal point of the medial malleolus of the tibia.²⁷

Assessing SA performance

An experienced tester, Tester 3, took the measurements of the SA of the PL. Participants sat on the edge of a table with thighs supported and hips and knees at 90 degrees flexion. Their feet did not touch the floor, and the lower leg was positioned vertical to the floor,

Figure 1 Assessing the reverse-action performance of the ankle evertor muscle using the I-to-V test: (a) side view (relaxed plantar flexion); (b) front view (starting position, with knees together and feet firmly planted on the floor; the bold line represents the letter I); (c) front view (end position, with the knees spread apart; the bold line represents the letter V).

with the ankle at rest in a plantar flexed position. Tester 3 stabilized the distal lower leg to prevent compensatory movement at the hip and knee joints and then placed a handheld dynamometer on the lateral side of the foot proximal to the fifth metatarsophalangeal joint (see Figure 2).⁸ A make test was used to assess strength because it is more reliable than a break test.²⁸ In a make test, the tester holds the handheld dynamometer stationary while the participant exerts maximal force against the dynamometer and examiner.²⁸ Tester 3 also gave standardised verbal encouragement to each participant with every effort. Additional contractions were instructed if the tester thought that a participant's effort was not complete or if the participant performed the movement incorrectly. To normalize these data to the data obtained from the SA method, normalized performance values were calculated as a percentage as follows: [(non-normalized value in kg / weight in kg) $\times$ 100].

Statistical analysis

All data except the EMG activity in both the RA and the SA methods were tested for a normal distribution using the Kolmogorov–Smirnov test. A bootstrap procedure with 1,000 replications was applied to test whether the reliability of the RA method was greater than that of the SA method.^{29,30} The intrarater test–retest reliability of the measurements of the PL muscle performance using the proposed RA method was assessed using an ICC(2, 2). The standard error of measurement (SEM) and 95% CI for the SEM were used to quantify intrarater reliability.

To investigate the correlation between the EMG data (% MVIC) and the performance values in the RA and SA conditions, we used one-tailed Spearman correlations ($\alpha = 0.05$). Performance values refer to the normalized distance between the medial tibial tuberosity (cm) in the RA condition and the normalized strength (kg) in the SA condition. EMG data for the peroneal muscles are presented using descriptive statistics (mean [SD]). The level of agreement between the RA and SA conditions was measured using a one-tailed linear correlation model ($\alpha = 0.05$). We conducted our statistical analysis using IBM SPSS Statistics, version 24.0 (IBM Corp., Armonk, NY).

RESULTS

Table 1 shows the detailed performance values for both sessions under each condition. In Table 2, the values for the two tests reveal that the intrarater test–retest reliability of the RA method was 0.95, and that for the SA method was 0.81. The difference in ICC between the two methods was 0.14 (95% CI: 0.01, 0.27). The SEM under both RA and SA conditions was low (Table 2).

During the muscle performance assessment under the RA condition, the activation level of the peroneal muscles was $30.3 \pm 15.1\%$ MVIC; in the SA condition, it was $84.7 \pm 4.8\%$ MVIC. Muscle activity using the RA assessment was strongly correlated with performance value ($\rho = 0.90$; 95% CI: 0.79, 0.95; $p = 0.01$), whereas muscle activity using the SA assessment was not ($\rho = 0.08$; 95% CI: $-0.26, 0.47$; $p = 0.63$).

Figure 2 Assessing the standard action performance of the ankle evtor muscle.

The PL performance measured by the RA method was found to be significantly correlated with the results from the SA method, which used the dynamometer-based assessment for the PL ($p = 0.40$; 95% CI: 0.03, 0.62; $p = 0.03$).

DISCUSSION

The principal findings of our study were that a method of assessing the RA performance of the PL muscle showed excellent intrarater test-retest reliability and exhibited a stronger correlation with the activation level of the peroneal muscles than the SA method. This is the first study to investigate the RA performance of the PL muscle using a simple method.

The PL muscle acts in ankle eversion and pronation.⁹ When testing the performance of this muscle, resistance is applied to both the lateral aspect of the foot and the medial-plantar region to induce both motions (ankle eversion and pronation), although it is difficult to apply resistance to both regions simultaneously.²¹ In the RA method, performing hip external rotation in the sitting position induces ankle inversion and supination, and

Table 1 Ankle Evertor Muscle Performance Values in Each Session

Condition	Mean (SD) normalized performance value percentage; range	
	Session 1	Session 2
Reverse action	31.9 (6.9); 16.0–41.0	31.4 (7.1); 14.0–41.0
Standard action	14.6 (3.3); 7.0–21.0	15.1 (3.6); 6.0–24.0

Table 2 Reliability and Standard Error of Measurement for Each Test

Condition	ICC (95% CI)	SEM (95% CI)
Reverse action	0.95 (0.87, 0.98)	1.63 (1.58, 2.20)
Standard action	0.81 (0.53, 0.92)	1.73 (1.23, 1.97)

ICC = intraclass correlation coefficient; SEM = standard error of measurement.

sufficient PL muscle activity (i.e., ankle eversion and pronation) is needed to overcome the stress of ankle inversion and supination. Ankle pronation is in a functional sense a relatively passive process driven by gravity, so peroneal muscles do not need to contract. However, the pronation action of the PL is necessary to prevent an ankle lateral sprain if the lateral region of the foot is placed on the ground—that is, if there is excessive supination of the ankle-foot complex during walking and landing after jumping. Therefore, when clinicians want to assess both ankle eversion and pronation simultaneously, the RA method is a way of measuring both, whereas the SA method measures only ankle eversion.

Both the RA and the SA methods demonstrated excellent test-retest reliability. Both methods also had a low SEM, indicating that the sessions testing the two methods were consistent. The CI of the RA method showed a smaller range than that of the SA method (see Table 2), indicating a more stable testing position; the greater range in CI of the SA method may be due to the difficulty of stabilizing and overpowering on resistance.³¹ In contrast, the testing position used for the RA method places the participant in a position that minimizes the need for external stabilization and encourages the participant to use active stabilization.

Peroneal muscle activity (% MVIC) had a significantly strong correlation with the performance value in the RA method; this suggests that the greater the activation of the peroneal muscle, the more the performance value increases. In comparison, using the SA method we found no significant correlation between muscle activity and PL strength. We are not aware of any study that has investigated peroneal muscle activation during a PL strength test. Greater EMG amplitude, which means a greater number of recruited motor units, does not

indicate greater strength because firing frequency also contributes to strength.^{17,32} Further studies are needed to investigate the relationship between firing frequency and the strength of the PL muscle. Another explanation is that the electrode used for the surface EMG in our study was attached only over the PL muscle, not other evertor muscles. The activation of other evertor muscles, such as the peroneus brevis, peroneus tertius, and extensor digitorum longus, may contribute to the strength of the ankle evertors in the SA method.⁹

Because of the absence of maximum resistance in the RA method, peroneal muscle activity showed a lower level of contractions than the SA method ($30.3 \pm 15.1\%$ MVIC in the RA method vs. $84.7 \pm 4.8\%$ MVIC in the SA method). Generally, peroneal muscle activity is low (39%) during gait.³³ Furthermore, some sports, such as volleyball, do not require maximal peroneal muscle activity. Volleyball players with ankle instability have been shown to have a lower RMS value pre-landing for the PL (26.2% MVIC) and a higher RMS value post-landing (55.8% MVIC) during a blocking movement.³⁴ Thus, lower muscle activity in the RA method than in the SA method is also clinically meaningful.

Our study has described a new method of assessing PL performance in a weight-bearing position that requires only a metric measuring tape. Although motor-driven dynamometers are valid tools for measuring the strength of the PL, their immobility and expense makes them impractical in the clinical setting.³⁵ And although handheld dynamometers have proved to be portable, inexpensive, reliable, and valid instruments,⁷ it has been suggested that they have limitations. First, a previous study reported difficulty with stabilization when strong participants overpowered the tester's resistance during an assessment of PL muscle strength.³¹ Second, participants tended to reduce their effort when they felt overpowered by the tester's resistance.³⁶ The RA method overcomes both these limitations by avoiding the need to use the tester's resistance.

It is important to note the limitations of our study. First, we did not measure the activity and strength of other lower leg muscles. The RA method uses hip external rotation with ankle eversion as a means of performing the RA, and the nature of this assessment setup implies that the measured performance is determined by active hip external rotation. The performance of the PL in the RA method may be a product of the hip external rotator and PL muscles in the hip–knee–ankle complex. Thus, clinicians should take into consideration that the primary goal of using the I-to-V test is to have an alternative method of testing the peroneal muscles rather than attempting to isolate them.

Second, the RA method required that participants be sitting so that the tester could focus the assessment on peroneal muscle activity. A standing position induces greater contraction of the hip muscles than the seated

position. Co-contraction of both hip and ankle muscles is also important in clinical tests such as the step-down. A previous study suggested that individuals with functional ankle instability have weak hip abductors and show increased ankle invertor moment during a forward step-down.¹ Individuals with ankle instability may need sufficient RA performance of the peroneal muscles and hip abductors to minimize the ankle inversion moment while stepping down. RA activity of the peroneal muscles can also reduce knee adduction moment while squatting or stepping down.

A third limitation of our study is that bony alignment was not quantified, although the participants were young, healthy people without severe misalignment. Last, although our study demonstrated the intrarater test–retest reliability of the RA method, we did not examine interrater reliability.

Further study is needed to investigate RA peroneal muscle activity in patient populations such as those with functional ankle instability. Specifically, further study should compare the muscle activity and strength of the peroneals, hip external rotators, and abductors between a group with functional ankle instability and a control group while they perform a step-down or one-legged squat. In addition, future studies should examine the potential correlation between the results of an RA test and the risk of a lateral ankle sprain in sports players with chronic ankle instability.

CONCLUSION

A new I-to-V test for measuring RA performance of PL muscle function was presented. The RA method is a simple, reliable, and inexpensive test, and it exhibited a strong positive correlation with PL muscle activity. Further validation in patient populations and examination of interrater reliability are recommended.

KEY MESSAGES

What is already known on this topic

Previous studies have focused on measuring the standard action (SA) of the peroneus longus (PL). The reverse action (RA) of the PL plays an important role in minimizing the moment of ankle inversion when an individual's foot is planted on the ground in a functional activity such as standing, squatting, or walking. However, no study has investigated peroneus longus muscle performance in terms of RA.

What this study adds

This study demonstrates that a method of assessing the RA performance of the PL shows excellent intrarater test–retest reliability. The RA method (using the I-to-V test) exhibited a stronger correlation with the activation level of the PL than the SA method. This study suggests that the RA method is a simple and inexpensive but highly reliable test and is useful for measuring the ability of the PL to separate between the fixed ankle–foot

complex and the moving tibia–fibula complex. Clinicians can select either the RA or the SA method to assess the PL.

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