Assessment of evertor weakness in patients with chronic ankle instability: Functional versus isokinetic testing

Romain Terrier a,b,⁎, Francis Degache c, François Fourchet d, Boris Gojanovic d, Nicolas Forestier a

a University Savoie Mont Blanc EA 7424 - Inter-university Laboratory of Human Movement Science, France
b Université de Savoie Mont Blanc EA 7424, Département des Sciences et Techniques des Activités Physiques et Sportives (STAPS), Université Savoie Mont Blanc, 73176 Le Bourget du lac cedex, France
c CEVRES Santé, Savoie Technolac, BP 322, 73377 Le Bourget du lac cedex, France
d University of Health Sciences, University of Applied Sciences and Arts Western Switzerland, Lausanne, Switzerland

⁎ Corresponding author at: Laboratoire Interuniversitaire de Biologie de la Motricité (E.A. 7424), Département des Sciences et Techniques des Activités Physiques et Sportives (STAPS), Université Savoie Mont Blanc, 73176 Le Bourget du lac, France.
E-mail address: romain.terrier@cevres.com (R. Terrier).

1. Introduction

Lateral ankle sprain is the most common musculoskeletal injury reported in physically active populations; in addition, the majority of patients with a history of lateral ankle sprain will sustain at least one additional sprain resulting in functional limitations and leading often to the defined condition of chronic ankle instability (Gribble et al., 2016). Indeed, it has been shown (Freeman et al., 1965; Gerber et al., 1998; Gribble et al., 2016; Waterman et al., 2010; Willems et al., 2002) that 40 to 70% of patients who suffered an initial ankle sprain were at risk for developing Chronic Ankle Instability (CAI). CAI has been described as a consequence of either or both mechanical and functional insufficiencies (Gribble et al., 2013). Mechanical instability is conditioned by ligament laxity, impaired arthokinematics or impingements. These deficits are usually managed by specific articular mobilizations (Hoch et al., 2012) and/or surgical approaches (Tourné et al., 2010). Functional instability is understood as sensorimotor joint control alterations (Hertel, 2002) mainly caused by proprioceptive (Munn et al., 2010) and/or ankle evertor muscles strength deficits (Pietrosimone and Gribble, 2012). Rehabilitation aims to restore these key parameters using supervised protocols, including specific proprioceptive and strengthening exercises.

Rehabilitation specialists also need to perform simple and reliable functional tests in order to (i) identify individuals suffering from functional deficits potentially leading to CAI and (ii) objectively assess improvements during the rehabilitation process. On the one hand, dynamic postural control deficits associated with CAI can be assessed using the well-known star excursion balance test (see Gribble et al., 2012 for a review). On the other hand, the eccentric performance of the ankle evertors is of primary interest as it takes part in the active control of the sudden ankle inversion (Collado et al., 2010; Graziani et al., 2001; Munn et al., 2003). While isokinetic eccentric muscular weakness has been considered as a factor responsible for CAI by some authors (Abdel-Aziem and Draz, 2014; David et al., 2013; Hartsell and Spaulding, 1999; Willems et al., 2002; Yildiz et al., 2003; Tropp, 1986), it is worth noting that there is no clear consensus about the relationships between evertor isokinetic weakness and CAI (Bernier et al., 1997; Kaminski et al., 1999; Kwon et al., 2013; Lentell et al., 1990). In

Abstract

Background: Ankle sprain is the most common sport-related injury and eccentric weakness of ankle evertors is regarded as a significant muscular deficit related to chronic ankle instability. However, the eccentric performance of the evertors is rarely assessed by clinicians because procedures used for research purposes (i.e. isokinetic tests) are not easily applicable in daily practice.

Methods: The present study assessed the ability of two different testing procedures to distinguish between groups of 12 healthy subjects or 12 patients suffering from chronic ankle instability. On the one hand, the strength of evertors was assessed with a gold standard isokinetic procedure. On the other hand, we assessed the ability of the subjects to control ankle inversion during weight bearing (functional standing test).

Findings: Data showed no significant difference between groups for isokinetic peak torque values normalized to body weight. Conversely, the functional test revealed a significantly impaired ability to control ankle inversion during weight bearing in subjects with chronic ankle instability.

Interpretation: This suggests that this easy-to-apply functional test is better suited compared to isokinetic testing procedures to assess weakness of evertors in patients suffering from chronic ankle instability. Moreover, this test may also be used to objectively monitor improvements during rehabilitation or progression in prevention protocols.
addition, such a deficit has rarely been evaluated in clinical practice (Eggart et al., 1993; De Nohonha and Borges, 2004; Plante and Wikstrom, 2013). Hence, isokinetic evaluation is still considered the gold standard procedure for research purposes, whereas this methodology is not easily transferable to daily practice due to cost, space requirements, portability and time consuming constraints considered as barriers by clinicians. Moreover, because subjects are sitting (i.e. not in weight bearing conditions) during the test, it is necessary to normalize torque data to body mass for comparison purposes. Alternative testing methods like hand-held dynamometers have been shown to be reliable and more practical for clinicians (Spink et al., 2010). However, it is worth considering that open kinetic chain conditions of ankle isokinetic testing and hand-held dynamometers never match the closed kinetic chain function of ankle evertors (Dvir, 2004; Edouard et al., 2011; Fourchet, 2013; Van Cingel et al., 2009). In other words, while ankle inversion strain is a weight bearing closed kinetic chain mechanism, evertors performance is systematically assessed using open kinetic chain tests (e.g. manual testing, hand-held or isokinetic dynamometers). In this context, an alternative practical functional test was recently proposed to assess ankle evertor weakness in closed kinetic chain in CAI patients (Terrier et al., 2014). This new functional testing option assesses the ability of the ankle to resist an inversion challenge in weight bearing conditions, through the use of a specific ankle inversion destabilization device called Myolux™ (Forestier and Terrier, 2011; Terrier and Forestier, 2015; Terrier et al., 2014). The Myolux™ device has been shown to primarily recruit ankle evertors under static (Forestier et al., 2015) and dynamic (Donovan et al., 2014; Forestier and Toschi, 2005) conditions.

To perform this test, which mainly requires eccentric evertor control, the Myolux™ device is equipped with a gyroscope sensor. This previous study demonstrated that an impaired control of weight bearing ankle inversion, revealed by significantly higher angular velocity peaks, can be regarded as a relevant discriminating factor between healthy and CAI subjects. Under such conditions, and in contrast to isokinetic tests, this functional weight bearing ankle inversion challenge is executed against body mass. This means that the test is more demanding for heavier subjects as body mass is taken into account in the net velocity values (this being the performance parameter). The performance of active joint protection does not require any normalization procedure.

The aim of the present study was to assess the ability of two different ankle eccentric evertor testing conditions to discriminate between healthy and CAI groups. The first condition referred to eccentric isokinetic tests, while the second referred to the new functional weight bearing test. We hypothesize that the functional weight bearing test is more sensitive to identify the weakness of ankle evertors compared to isokinetic testing procedures.

2. Material & Methods

2.1. Subjects

A group of healthy subjects (healthy group) and a group of CAI subjects (CAI group) participated in the study. As presented in the Table 1, the healthy group included 12 healthy active subjects (four males and eight females; mean age 19(1.5) yr; mean mass 62.1(10.9) kg; mean height 169.3(8.3) cm) with no history of ankle sprain, neurological or motor dysfunctions. The CAI group included 12 CAI subjects (nine males and three females; mean age 19.5(1.9) yr; mean mass 71.9(16.4) kg; mean height 175.5(11.6) cm). Exclusion and inclusion criteria for CAI subjects have been applied according to the recommendations of the International Ankle Consortium (Gribble et al., 2013). Exclusion criteria consisted of any history of previous surgery to musculoskeletal structures (i.e., bones, joint structures, nerves) in either lower extremity; any history of a fracture in either lower extremity requiring realignment; and any acute injury to musculoskeletal structures of other joints of the lower extremity that impacted joint integrity and function (i.e., sprains, fractures) in the previous 3 months. For the CAI group, inclusion criteria were a minimum of two lateral sprains on the same ankle, the most recent one during the last year but >3 months prior to study enrolment; a feeling of ankle joint instability, and frequent ankle “giving way”. No member of the CAI group performed rehabilitation exercises during the study. A non-validated French translation of the Ankle Instability Instrument (Docherty et al., 2006) was provided to the subjects. As recommended by the International Ankle Consortium (Gribble et al., 2013), all subjects included in the CAI group answered “yes” to at least 5 yes/no questions including question 1 (see table 1 for data about inclusion criteria). Finally, each subject declared to experience at least one episode of ankle “giving way” per month. All CAI subjects were affected by unilateral instability and their unstable ankle (dominant or not) was tested. The distribution between dominant and non-dominant ankles tested in the healthy group matched the distribution in the CAI group. The study was approved by the local research ethics committee and subjects’ informed consent was obtained in conformity with international standards (Harriss and Atkinson, 2013).

2.2. Task and apparatus

2.2.1. Eccentric isokinetic test

Peak torques (PT) of ankle invertors and evertors were tested by the same examiner using an isokinetic HUMAC NORM® dynamometer (Humac Norm, Humac, CA, USA). Data were acquired by a personal computer using the HUMAC software, which calculated and displayed torque and joint displacement values. Calibration of the isokinetic dynamometer with the computing software was performed using certified weight before data collection.

2.2.2. Functional test: eccentric weight bearing ankle inversion control

This previously described functional test (Terrier et al., 2014) consisted of measuring angular ankle inversion velocity during a weight bearing ankle inversion challenge in healthy and CAI subjects. This test was performed using a custom version of a Myolux™ device (Myolux Medik e-volution™ developed from Myolux Medik II™, CEVRES Santé, France) equipped with an articulator located under the rear foot and described in previous papers (e.g. Donovan et al., 2014; Donovan et al., 2015; Forestier and Terrier, 2011; Forestier and Toschi, 2005; Terrier et al., 2014). This articulator generated angular displacements along the physiological subtalar axis (also called Henke axis) to induce ankle inversion and eversion movements. In weight bearing conditions, the ankle automatically moves in inversion, requiring eccentric evertor activation to control this movement. The articulator of the custom device was equipped with an Inertial Measurement Unit (Shimmer3, Dublin, Ireland) to capture from the integrated gyroscope angular velocity signals associated with inversion movements at 51.2 Hz. Signals were then analysed with a custom software developed in Matlab™ (Analyse™, GRAME, Quebec).

Table 1: Subjects demographics and inclusion criteria for the both experimental groups.

<table>
<thead>
<tr>
<th>Subjects demographics</th>
<th>Healthy (n = 12)</th>
<th>CAI group (n = 12)</th>
<th>t-Test results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male: 4 Female: 8</td>
<td>Male: 9 Female: 3</td>
<td></td>
</tr>
<tr>
<td>Age (mean ± SD; yr)</td>
<td>19(1.5) 19.5(1.9)</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Mass (mean ± SD; kg)</td>
<td>62.1(10.9) 71.9(16.4)</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Height (mean ± SD; cm)</td>
<td>169.3(8.3) 175.5(11.6)</td>
<td>NS</td>
<td></td>
</tr>
</tbody>
</table>

Inclusion criteria

Yes answers to all questionnaire

<table>
<thead>
<tr>
<th>(mean ± SD)</th>
<th>7.2(2.2)</th>
<th>p &lt; 0.001</th>
</tr>
</thead>
</table>
| Previous sprains of the tested ankle
| (mean ± SD) | 3.6(2.6) | p < 0.001 |
2.3. Procedure

The order of experimental tests (eccentric isokinetic and functional test) was randomized between subjects so that half received one order and half received the other order.

2.4. Eccentric isokinetic test

The subject’s installation was standardized \((\text{Davies, 1992; Genty and Schmidt, 1998; Kaminski and Hartsell, 2002; Kaminski et al., 1999})\) according to the apparatus recommendations. As illustrated in Fig. 1, the subject was in lying supine, knee bent at 55° on the tested side, and the lower leg in horizontal position with the thigh being strapped to the table. The dynamometer axis was aligned with the axis of inversion-inversion rotation of the joint: passing through the heel, the talocalcaneal joint, and the centre of the axis between the lateral and the medial malleolus. Straps stabilized foot, leg, and pelvis (Fig. 1). Handles were set on both sides to hold on to, in order for the subject to perform better (Kaminski and Hartsell, 2002; Kaminski et al., 1999).

The test was performed at low velocity \((\text{i.e. } 30° \text{· s}^{−1})\) according to previous studies (Hartsell and Spaulding, 1999; Kaminski et al., 1999; Munn et al., 2003; Spink et al., 2010; Willems et al., 2002). The eccentric mode was chosen according to its relation with the sprain protection mechanism (Munn et al., 2003; Terrier and Forestier, 2015; Terrier et al., 2014). Each subject followed the same standardized protocol: 15 repetitions for familiarization and warm-up, followed by six maximal repetitions. The average performance of the six repetitions was considered for analysis. The tests were made on both ankles in random order. Subjects were verbally encouraged and blinded to the curves on the screen (Hartsell, 1994). Isokinetic assessment of the ankle invertors and evertors was shown to be valid and reliable (Baumhauer et al., 1995; Bernier et al., 1997; Hartsell, 1994).

2.5. Functional test

Subjects (healthy and CAI groups) were asked to stand on their tested leg with the knee fully extended. Subjects raised their forefoot and applied 100% of body weight on their rearfoot positioned on the articulator of the destabilization device. To increase inversion range of motion, the articulator was positioned on an 2.5 cm elevated platform (Fig. 2A). A slight touch of the fingers on the front wall was allowed for balance. From this starting position, subjects were asked to control the ankle inversion movement. The given instructions were “go down as slowly as possible while keeping your knee in full extension and without laterally moving your hips”. Lateral movements of the hips and the trunk were limited by hip contact (tested side) against the wall. Each subject performed six repetitions. In order to ensure that real inversion movements were performed in accordance with the aim of the study, loud verbal encouragements were given to all the subjects and during each trial. Additionally each inversion movement was visually controlled in order to avoid compensations. A trial was repeated if the experimenter considered that subject made a plantar flexion instead of inversion. In this study, there were no failed trials because all subjects received strict instructions and had the opportunity to perform 15 repetitions for familiarization and warm-up followed by six inversion movements as slowly as they could. When a subject failed to adequately control ankle inversion, and thus performed a sudden and quick ankle inversion, the analysed parameters were consequently altered and revealed an impaired control of weight bearing ankle inversion. Each repetition ended when the fifth metatarsal head touched the ground (Fig. 2B). Subjects then moved back to the starting position for the next repetition. The average performance of the six repetitions was considered for analysis.

3. Data analysis

Regarding the eccentric isokinetic test, the reported values were the peak torque, in Newton-meter (N·m) for the evertors and invertors. Absolute peak torque was preferred to mean peak torque measures according to Munn et al. (2003). As previously highlighted by several research groups (David et al., 2013; Willems et al., 2002), normalized torque values are more relevant since ankle inversion and eversion moments usually occur in a closed kinetic chain, and thus against body weight.

Regarding the functional test, the angular velocity peaks were automatically determined for each trial. Peak values were selected for analysis rather than angular average values, because a neuromuscular deficit of ankle evertors is known to be related to a sudden incapacity to control weight bearing ankle inversion (Terrier et al., 2014).
3.1. Statistical analyses

The Shapiro–Wilk test was used to test for normal distribution of all dependent variables. As all data sets were normally distributed, t-tests for independent samples were used to compare data related to each analysed parameter between the two independent groups. A 0.05 alpha threshold was adopted throughout (Statistica StatSoft Inc., Tulsa, USA). 95% confidence intervals as well as effect sizes (Cohen’s d) also were computed for each parameter. Using Cohen’s criteria (Cohen, 1988), effect sizes were considered as trivial (<0.2), small, (0.2 < d < 0.5), moderate (0.5 < d < 0.8), or large (d > 0.8) (Hopkins and Hewson, 2001).

4. Results

Results from all ankle evertor eccentric tests (3 parameters from isokinetic tests and 1 parameter from the functional test) are detailed below and summarized in Table 2. Important for interpretation is the fact that higher isokinetic values (torques or ratios) correspond to better performance, whereas an increase of absolute values (and thus a decrease of negative values) in the functional test (angular velocity peaks) corresponds to lower performance. In addition, velocity during weight bearing inversion challenge is negative due to the eccentric mode used for evertors performance assessment.

The t-tests for independent samples revealed that isokinetic evertors peak torques were significantly lower (t = −2.19, p = 0.039) for the healthy group (27.9(8.8), 95% CI [22.3, 33.5] N·m) in comparison with the CAI group (36.3(11.6), 95% CI [28.9, 43.7] N·m). The associated Cohen’s d effect size was 0.85 (95% CI [−1.68, 0.03]) and represented a large effect. However, as illustrated in Fig. 3, there was no significant difference (t = −1.35, p = 0.19) between groups regarding isokinetic evertors peak torques indexed to body weight (0.42(0.12), 95% CI [0.34, 0.49] N·m·kg⁻¹ vs. 0.49(0.12), 95% CI [0.41, 0.56] N·m·kg⁻¹ for healthy and CAI groups respectively). The associated effect size was moderate (d = 0.61, 95% CI [−1.43, 0.26]).

Additionally, the analysis of eccentric evertors/invertors torque ratios did not reveal any significant difference (t = −1.33, p = 0.20) between the healthy (0.67(0.28), 95% CI [0.49, 0.85]) and the CAI group (0.81(0.23), 95% CI [0.66, 0.95]). The associated effect size was moderate (d = 0.57, 95% CI [−1.4, 0.3]). In the functional test, angular velocity peaks was significantly different between the two groups (3.48, p = 0.002) as illustrated on Fig. 4. Mean velocity peak values were significantly lower for the CAI group (−100.2(33.5), 95% CI [−78.9, −121.5] deg·s⁻¹) in comparison with the healthy group (−62.5(17.3), 95% CI [−51.7, −73.3] deg·s⁻¹) with a large effect size (d = 1.48, 95% CI [−2.38, −0.6]). As previously mentioned, significant lower negative values in CAI group corresponded to an impaired performance and revealed a significant weakness of ankle evertors in CAI subjects.

5. Discussion

The aim of the present study was to assess the ability of two different ankle evertor eccentric testing conditions to discriminate between healthy and CAI groups. The first condition referred to eccentric isokinetic tests (reference procedure), the second condition referred to a new functional weight bearing test. Two main issues related to recent publications in this field motivated this work. First, there is no clear consensus on the relationship between CAI and eccentric weakness of ankle evertors, as assessed by isokinetic dynamometer. Some authors hypothesized these incongruent results should be the consequence of testing conditions that never matched the evertors’ testing conditions to discriminate between healthy and CAI patients (Edouard et al., 2011; Fourchet, 2013). Second, while considered the gold standard for laboratory studies, isokinetic testing procedure is not easily transferable to clinical practice, whereas some functional alternative do exist (Terrier et al., 2014).

To our knowledge, the present study was the first one to investigate whether an impaired control of weight bearing ankle inversion measured by the Myolux™ device can be considered a relevant factor to distinguish healthy subjects from CAI patients.

Table 2
Main results for three eccentric parameters and the functional test.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Healthy group</th>
<th>CAI group</th>
<th>p-Values</th>
<th>Cohen’s d coefficient</th>
<th>CAI/healthy performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evertors peak torque (N·m)</td>
<td>27.9(8.8)</td>
<td>36.3(11.6)</td>
<td>0.039</td>
<td>0.85</td>
<td>30.1%*</td>
</tr>
<tr>
<td>Normalized evertors peak torque (N·m/kg)</td>
<td>0.42(0.12)</td>
<td>0.49(0.12)</td>
<td>0.19</td>
<td>0.61</td>
<td>16.6 NS</td>
</tr>
<tr>
<td>Torque ratio evertors/invertors (%)</td>
<td>67(28)</td>
<td>81(28)</td>
<td>0.2</td>
<td>0.57</td>
<td>20.9% NS</td>
</tr>
<tr>
<td>Angular velocity peak (deg/s)</td>
<td>−62.5(17)</td>
<td>−100.2(33.5)</td>
<td>0.002</td>
<td>1.48</td>
<td>−60.3*</td>
</tr>
</tbody>
</table>

* p < 0.05.

Fig. 3. Normalized ankle evertors’ peak torque data (N.m/kg) obtained during eccentric isokinetic testing.

Fig. 4. Performance during functional test (weight bearing ankle inversion control). Data showed significant lower performance (lower negative angular velocity peaks) for CAI subjects (right), in comparison with healthy subjects (left). *p < 0.01.
Even if the weight difference is not statistically significant between groups, subjects from CAI group were on average heavier than healthy one and thus, as highlighted in previous research (David et al., 2013; Willems et al., 2002), normalization of isokinetic torque values against body weight facilitates the statistical comparison of muscle performance in subjects with different morphologies. Normalized torque values are also more relevant because inversion moment generated at the ankle usually takes place in a closed kinetic chain, against body weight. This observation is strengthened by the specific purpose of the present study as it aimed to compare results from an isokinetic testing procedure versus a functional weight bearing ankle inversion control task. Finally the normalized peak torque values of evertor muscles, considered as the most relevant isokinetic parameter, revealed no significant differences between healthy and CAI groups. It may therefore be concluded that isokinetic data did not reveal any weakness in ankle evertors in CAI people in the present study.

Contrary to isokinetic testing and in accordance with a previous experimentation (Terrier et al., 2014), the functional test highlighted a significant weakness of evertors in the CAI group compared to the healthy group. Indeed, during the ankle inversion challenge, CAI subjects showed significantly lower (negative) angular velocity peaks. The analysis of 95% confidence intervals from this study suggested an angular velocity threshold for identifying a deficit in eccentric ankle inversion control around −75°/s. While healthy subjects never reach this limit, all CAI subjects performed trials with higher negative angular velocity peak values. Although this test does not directly assess the evertor strength of the subject, such a result can be considered as an expression of a deficit in eccentric control (i.e. evertors) during a potentially traumatic ankle inversion movement. In other words, lower negative angular velocity peaks (i.e. higher absolute values) during ankle inversion challenge reveal a strong sensorimotor deficit. More precisely, this simple parameter can be considered as the expression of an eccentric muscular weakness assessed under functional (weight bearing closed kinetic chain) conditions (Terrier et al., 2014). We have also reported in previous work (Terrier and Forestier, 2015) a threshold parameter distinguishing healthy and CAI subjects without the gyroscope sensor. These data showed that none of the CAI patients could perform 15 repetitions of controlled inversion/explosive eversion against body weight, while all healthy subjects could perform 15 or more repetitions. 95% interval confidence from these data revealed that 15 repetitions could be considered as a threshold value. The central (cortical) origin of such sensorimotor deficits associated with chronic ankle instability has been clearly established (Pietrosimone and Gribble, 2012), but to our knowledge, clinicians cannot assess this functional deficit with use of a practical parameter in clinical practice. Our study shows that the functional device tested can fill this gap.

The two testing procedures used in this study led to contrasting conclusions about the eccentric weakness of evertors in CAI subjects. These results likely question the choice of the testing procedures. As the functional test used here clearly showed a deficit in CAI patients, the present results suggested that isokinetic tests didn’t represent the most accurate way to measure evertors weakness in chronically unstable ankles. This is most likely a consequence of testing procedures (i.e. isokinetics) that never matches the real world functional recruitment of evertor muscles.

The unique effects of rehabilitation exercises performed in closed kinetic chain has been widely emphasized for several years, due to the differences in muscle action, joint receptor function and coordination allowed by this type of exercise (Kwon et al., 2013; Webster and Gribble, 2010). More specifically several experimentalizations evaluated in a review by Webster and Gribble (2010) provided support for the efficacy of functional closed-chain interventions (e.g. the use of unstable surfaces) for patients with CAI. It may then appear of interest to apply this “recent” rehabilitation paradigm into the evaluation phase already, using a functional weight bearing and closed kinetic chain evaluation of the ankle evertor function rather than an analytic non-weight bearing and opened kinetic chain evaluation like isokinetic testing, even if considered as the gold standard in research. There are some limitations in this study that need to be considered when interpreting the findings. First of all, because of strict exclusion and inclusion criteria, male and female ratios are different between our groups. However, these ratios above all influence body weight and demographics data are not statistically different between groups (Table 1). Moreover, as isokinetic data are normalized to body mass and weight is taking into account in the net velocity values for the weight bearing functional test, we think that uneven male to female ratio between groups is not a limitation for this study. It is also worth noting that the small sample size most likely affected the strength of the statistical analysis according to the power and effect size. We are nevertheless confident this study may help to determine that the functional testing method, easier to implement in daily practice, is better than the isokinetic method at discriminating between healthy individuals and those with CAI.

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