A Novel Device Using the Nordic Hamstring Exercise to Assess Eccentric Knee Flexor Strength: A Reliability and Retrospective Injury Study

Hamstring strain injury (HSI) is the most common injury type in a number of sports and is notorious for its high recurrence rate. A high proportion of HSIs are thought to occur during the terminal swing phase of high-speed running, when the hamstrings are required to perform a forceful eccentric contraction. Lower eccentric knee flexor strength has been reported as a risk factor for future HSI, indicating the importance of eccentric strength for HSI avoidance. Further, previously strained hamstrings display reduced levels of eccentric knee flexor strength compared to those in the uninjured contralateral limb, which may partially explain why a previous HSI is the primary risk factor for future injury.

The purposes of this investigation were (1) to determine if a novel device, designed to measure eccentric knee flexor strength via the Nordic hamstring exercise on the device on 2 separate occasions, was able to detect weakness in previously injured elite athletes and (2) to determine normative values for eccentric knee flexor strength derived from the device in individuals without a history of unilateral HSI.

**STUDY DESIGN:** Reliability and case-control injury study.

**OBJECTIVES:** To determine if a novel device designed to measure eccentric knee flexor strength via the Nordic hamstring exercise displays acceptable test-retest reliability; to determine normative values for eccentric knee flexor strength derived from the device in individuals without a history of hamstring strain injury (HSI); and to determine if the device can detect weakness in elite athletes with a previous history of unilateral HSI.

**BACKGROUND:** HSI and reinjury are the most common cause of lost playing time in a number of sports. Eccentric knee flexor weakness is a major modifiable risk factor for future HSI. However, at present, there is a lack of easily accessible equipment to assess eccentric knee flexor strength.

**METHODS:** Thirty recreationally active males without a history of HSI completed the Nordic hamstring exercise on the device on 2 separate occasions. Intraclass correlation coefficients, typical error, and percentage of residual weakness were determined using the most reliable measurement. An additional 20 elite athletes with a unilateral history of HSI within the previous 12 months performed the Nordic hamstring exercise on the device to determine if residual eccentric muscle weakness existed in the previously injured limb.

**RESULTS:** The device displayed high to moderate reliability (intra-class correlation coefficient = 0.83-0.90; typical error, 21.7-275 N; typical error as a coefficient of variation, 5.8%-8.5%; minimal detectable change at a 95% confidence level, 60.1-76.2 N). Mean ± SD normative eccentric flexor strength in the uninjured group was 344.7 ± 61.1 N for the right and 361.2 ± 65.1 N for the right side. The previously injured limb was 15% weaker than the contralateral uninjured limb (mean difference, 66.5 N; 95% confidence interval: 1.4, 98.5; P = .04), and 18% weaker than the normative right limb (mean difference, 66.5 N; 95% confidence interval: 18.0, 115.1; P < .01).


**KEY WORDS:** Dynamometry, hamstring, strain injury.

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METHODS

Participants

Thirty subelite, male athletes, most competing in Australian football, rugby (league, union, or touch), soccer, or sprinting, participated in the section of the study that assessed the test-retest reliability of the device and determined normative flexor strength values. In addition, 20 professional elite athletes from Australian football, rugby union, and track and field, with a history of HSI within the previous 12 months, participated on a single occasion to assess the ability of the device to detect strength deficits in previously injured athletes. Athletes who did not have magnetic resonance imaging performed to confirm the hamstring injury, did not show a lesion on magnetic resonance imaging, or had a history of traumatic knee injury were excluded from the study. All participants were free of any current injury to the lower limbs and were fully active in their chosen sport at the time of testing. All testing procedures were approved by the Queensland University of Technology Human Research Ethics Committee, and participants gave informed written consent prior to testing, after having all procedures explained to them.

Experimental Design

For the collection of reliability and normative data on subjects without a history of HSI in the previous 12 months, the 30 participants reported to the laboratory on 3 separate occasions. The first occasion was a familiarization session and the following 2 occasions were used to determine eccentric knee flexor strength via the novel device. All participants with a history of an HSI within the prior 12 months, who participated in the second part of the study, were performing the NHEs as part of their regular training routine, eliminating the need for a familiarization session. Therefore, they completed a single testing session.

FIGURE 1: Performing the Nordic hamstring exercise using the novel device (progressing from left to right). The participant controls the speed of the fall by forceful eccentric contraction of the knee flexors. After the completion of the exercise, the participant slowly returns to the starting position by pushing back up with both hands (not shown). The ankles are secured independently in individual custom-made braces.

FIGURE 2: (A) The experimental device with individual ankle braces, padded cushion for knee support, and wooden base. (B) Close-up view of the ankle brace, load cell organization, and pivot.
TABLE 1

<table>
<thead>
<tr>
<th></th>
<th>Test 1, N⁺</th>
<th>Test 2, N⁺</th>
<th>Effect Size¹</th>
<th>ICC¹</th>
<th>TE, N⁺</th>
<th>%TE³</th>
<th>MDC⁺, N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bilateral testing peak force³</td>
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<tr>
<td>Left</td>
<td>366.4 ± 677</td>
<td>371.4 ± 60.5</td>
<td>-0.12 (-0.35, 0.11)</td>
<td>0.83 (0.67, 0.91)</td>
<td>275 (213, 369)</td>
<td>8.5 (6.7, 11.6)</td>
<td>76.2</td>
</tr>
<tr>
<td>Right</td>
<td>378.4 ± 68.4</td>
<td>391.6 ± 670</td>
<td>-0.20 (-0.36, -0.03)</td>
<td>0.90 (0.81, 0.95)</td>
<td>217 (173, 292)</td>
<td>5.8 (4.6, 7.9)</td>
<td>60.1</td>
</tr>
<tr>
<td>Left-right ratio</td>
<td>0.97 ± 0.11</td>
<td>0.96 ± 0.13</td>
<td>0.09 (-0.20, 0.37)</td>
<td>0.76 (0.55, 0.88)</td>
<td>0.06 (0.05, 0.08)</td>
<td>6.0 (4.8, 8.2)</td>
<td>0.17</td>
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<td>Unilateral testing peak force³</td>
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<tr>
<td>Left</td>
<td>351.3 ± 55.5</td>
<td>356.8 ± 65.6</td>
<td>-0.09 (-0.37, 0.19)</td>
<td>0.73 (0.51, 0.86)</td>
<td>32.3 (25.7, 43.5)</td>
<td>10.2 (8.1, 14.0)</td>
<td>89.5</td>
</tr>
<tr>
<td>Right</td>
<td>380.9 ± 60.4</td>
<td>370.4 ± 54.7</td>
<td>0.18 (-0.17, 0.54)</td>
<td>0.56 (0.26, 0.76)</td>
<td>38.8 (30.9, 52.1)</td>
<td>11.0 (8.7, 15.1)</td>
<td>107.5</td>
</tr>
<tr>
<td>Left-right ratio</td>
<td>0.52 ± 0.13</td>
<td>0.96 ± 0.13</td>
<td>-0.31 (-0.70, 0.08)</td>
<td>0.40 (0.05, 0.66)</td>
<td>0.09 (0.07, 0.11)</td>
<td>10.1 (8.0, 13.9)</td>
<td>0.25</td>
</tr>
<tr>
<td>Bilateral testing average peak force³</td>
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<tr>
<td>Left</td>
<td>336.3 ± 63.8</td>
<td>344.7 ± 61.1</td>
<td>-0.13 (-0.34, 0.07)</td>
<td>0.85 (0.71, 0.93)</td>
<td>24.7 (19.7, 33.2)</td>
<td>8.4 (6.6, 11.5)</td>
<td>68.5</td>
</tr>
<tr>
<td>Right</td>
<td>349.4 ± 64.8</td>
<td>361.2 ± 65.1</td>
<td>-0.18 (-0.36, 0.00)</td>
<td>0.89 (0.78, 0.95)</td>
<td>22.1 (17.6, 29.7)</td>
<td>6.5 (5.1, 8.8)</td>
<td>61.3</td>
</tr>
<tr>
<td>Left-right ratio</td>
<td>0.96 ± 0.11</td>
<td>0.95 ± 0.13</td>
<td>0.11 (-0.08, 0.28)</td>
<td>0.85 (0.71, 0.93)</td>
<td>0.04 (0.04, 0.06)</td>
<td>4.6 (1.7, 5.9)</td>
<td>0.11</td>
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<tr>
<td>Unilateral testing average peak force³</td>
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<tr>
<td>Left</td>
<td>321.4 ± 54.0</td>
<td>326.4 ± 64.2</td>
<td>-0.04 (-0.28, 0.21)</td>
<td>0.79 (0.61, 0.90)</td>
<td>27.6 (22.0, 33.2)</td>
<td>9.5 (7.5, 13.0)</td>
<td>76.5</td>
</tr>
<tr>
<td>Right</td>
<td>341.8 ± 50.9</td>
<td>335.8 ± 54.7</td>
<td>0.11 (-0.13, 0.35)</td>
<td>0.80 (0.63, 0.90)</td>
<td>241 (192, 32.5)</td>
<td>79 (6.2, 107)</td>
<td>66.8</td>
</tr>
<tr>
<td>Left-right ratio</td>
<td>0.94 ± 0.12</td>
<td>0.96 ± 0.14</td>
<td>-0.19 (-0.54, 0.15)</td>
<td>0.55 (0.24, 0.76)</td>
<td>0.08 (0.06, 0.10)</td>
<td>8.7 (6.9, 11.9)</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Abbreviations: ICC, intraclass correlation coefficient; MDC⁺, minimal detectable change at 95% confidence level; TE, typical error; %TE, typical error as a coefficient of variation.

*Values are mean ± SD.
Values in parentheses are 95% confidence interval.
Peak force is the highest maximal force recorded from 6 trials.
Average peak force is the mean of maximal force recorded from each of the 6 trials.

Injury History

For all athletes recruited to the second part of the study, details of any prior injury for the preceding 12 months were ascertained from their club clinician. Details obtained included which limb was injured (dominant, nondominant), muscle injured (biceps femoris long head, biceps femoris short head, semimembranosus, semitendinosus), location of injury (proximal or distal, muscle belly or muscle-tendon junction), activity type performed at time of injury (running, kicking), and grade of injury (I, II, III).

Data Analysis

For the reliability and normative part of the study, force data were transferred to a personal computer at 1000 Hz through a 16-bit PowerLab 26T recording unit (ADInstruments Pty Ltd, Bella Vista, Australia). Subsequently, the peak force for each trial for both limbs (left and right) and conditions (bilateral and unilateral) was determined using LabChart 7.3 (ADInstruments Pty Ltd). The maximal force generation was expressed both as the average of the peak force from the 6 trials (average peak force) and as the single highest peak of 6 trials (peak force). The between-limb force ratio was calculated as the left-right limb ratio. The between-limb force ratios were calculated as recommended, using log-transformed raw data followed by back

TABLE 2

Comparisons of Eccentric Strength Within and Between Groups

<table>
<thead>
<tr>
<th>Control (Normative)</th>
<th>History of Injury</th>
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<tbody>
<tr>
<td></td>
<td>Left Limb</td>
</tr>
<tr>
<td>Eccentric knee flexor strength, N</td>
<td>344.7 ± 61.1</td>
</tr>
</tbody>
</table>

*Significantly weaker than the other 3 limbs (P<.05).
transformation.

For the group of subjects with a recent history of HSI, force data were transferred to a personal computer at 100 Hz through a wireless USB base station receiver (Mantracourt Electronics Ltd). In this group, only the average peak force was determined, based on the peak force from each of the 6 bilateral trials.

Statistical Analysis
In the group without a history of HSI, descriptive statistics of all force variables and between-limb force ratios were calculated independently for the left and right sides. Intraclass correlation coefficient (ICC), typical error (TE), and TE as a coefficient of variation (%TE) were calculated to determine the magnitude of variability from the first to the second testing occasion.10,11 Minimal detectable change at a 95% confidence level was calculated as $TE \times \sqrt{2}$. We subjectively considered the data based on previously published quantitative guidelines where an ICC of 0.90 or greater was regarded as high, between 0.80 and 0.89 as moderate, and 0.79 or less as poor,21 and a %TE of 10% or less was set as the level at which a measure was considered reliable.22 Effect size (ES) was determined by comparing data from the first and second testing occasions (test 1 minus test 2) to evaluate the magnitude of systematic bias. An ES (mean difference divided by pooled standard deviation) of less than 0.2 was expected.

For the data collected on the group with a prior history of HSI, statistical analysis was performed using JMP Version 10.0.2 (SAS Institute Inc, Cary, NC). The data from these previously injured elite athletes were compared to the normative data from the first group, using a split-plot design, linear mixed model, fitted by the restricted maximum likelihood method, with fixed factors of group (uninjured/injured) and limb (left/right or uninjured/injured, depending on group) and a random factor of subject identification number. Where significant effects were detected, post hoc least-squares difference testing was used to identify which variables differed. Significance was set at $P<.05$, and ES was calculated using Cohen $d$. Data are reported as mean ± SD.

RESULTS

Group Without a Previous History of HSI

Descriptive statistics, ES, and test-retest reliability data for all force variables are presented in Table 1. Overall, using ICC as the measure of test-retest reliability, absolute force measurements taken during the bilateral condition (ICCs ranged from 0.83 to 0.90) were more reliable than those collected during the unilateral condition (ICCs ranged from 0.56 to 0.80). For between-limb force asymmetries, only the ratios based on the average peak force during the bilateral condition had acceptable reliability (ICC = 0.85)20; 95% confidence interval [CI]: 0.71, 0.93). Similarly, when using %TE to examine reliability, the results from the bilateral conditions (%TE ranged from 5.8% to 8.5%) were more reproducible than those from the unilateral conditions (%TE ranged from 7.9% to 11.0%). Furthermore, between-limb ratios were most reliable when based on the average peak force calculated from the bilateral testing condition (%TE, 4.6%; 95% CI: 3.7%, 5.9%).

Athletes With a History of HSI

In the 20 previously injured athletes, HSIs were most common in the non-dominant limb (13 of 20), in the biceps femoris long head (15 of 20), and at the proximal or distal muscle-tendon junction (14 of 20), and were predominantly grade 1 strains (13 of 20) that most often occurred during high-speed running (16 of 20). The average time since the most recent HSI was 5.7 months.

A significant group-by-limb interaction effect was detected ($P = .0378$), and post hoc least-squares difference testing found that the previously injured limb was weaker than the contralateral uninjured limb (mean difference, 50.3 N; 95% CI: 25.7, 74.9; $P = .0002$; ES, 0.46) and also weaker than the left limb (mean difference, 50.0 N; 95% CI: 1.4, 98.5; $P = .0437$; ES, 0.60) and right limb (mean difference, 66.5 N; 95% CI: 18.0, 115.1; $P = .0080$; ES, 0.79) of the uninjured normative group (Table 2). No differences existed between the uninjured limb from the group with a history of HSI and the left ($P = .9891$) and right ($P = .5064$) limbs from the normative uninjured group (Table 2).

DISCUSSION

The major findings of the current study are that (1) the experimental device showed high to moderate test-retest reliability for measurements when the NHE was performed bilaterally but poor reliability during unilateral testing, and (2) elite athletes with a unilateral history of HSI within the previous 12 months displayed significant eccentric knee flexor weakness in their injured limb compared to their uninjured limb and to the limbs of uninjured recreational athletes.

For the measurement of absolute strength, only when the NHE was completed bilaterally, and when peak force was averaged across 6 trials, did the measure display moderate reliability (ICC = 0.85-0.89). Measurements made with an isoinertial (ICC ranged from 0.83 to 0.97)12,14,15 or handheld (ICC = 0.90)23 dynamometer have been reported to have similar or slightly higher levels of reliability. The only previous study, to our knowledge, that examined the reliability of between-limb eccentric knee flexor strength ratios using an isokinetic dynamometer reported a lower test-retest reliability (ICC = 0.69)22 than that reported in this study (average peak force with bilateral testing, ICC = 0.85).

The finding that a previously strained hamstring still displayed weakness in comparison to the uninjured side when tested eccentrically, despite “successful” rehabilitation, is consistent with data previously published.13,19 The percentage difference in eccentric strength between
limbs, reported here in the injured cohort (15%), is similar to previously reported data using isokinetic dynamometry (11%-13%). It may be argued that it would have been appropriate to normalize the force measurements derived from the experimental device to the stature and weight of the participant. However, we did not believe that this would be critical. Due to the nature of the NHE, all athletes reach a critical point in the range of motion where the ever-increasing external load from gravity acting on the upper body exceeds the maximal eccentric hamstring strength of the athlete. While the position in which this critical point in the range of motion occurs will be influenced by individual anthropometric characteristics and strength level, reaching this critical point will require maximal force generation of the knee flexors. We have noted low correlations between height or weight and maximal eccentric knee flexor strength from the novel device ($R^2 = 0.01-0.13$).

The major limitation of the current study is the retrospective nature of data collection on those with a previous history of HSL, which precludes determining whether the eccentric weakness seen in the previously injured limb was the cause or the result of injury. It should also be noted that all participants in the reliability aspect of the current study undertook a familiarization session, and, as such, the reliability data presented are only applicable to individuals with some exposure to the NHE. The device itself is limited, as it cannot control movement speed or determine angle of peak torque of the knee flexor muscle group, which is possible through the use of an isokinetic dynamometer.

**CONCLUSION**

A **NOVEL FIELD-TESTING DEVICE THAT** uses the NHE as a means to measure eccentric knee flexor strength and between-limb strength asymmetry demonstrated high to moderate levels of test-retest reliability during bilateral testing. Using the device, residual eccentric weakness of previously injured elite athletes, of a magnitude similar to that previously measured with other methods, was also identified. This portable device offers an alternative to current dynamometry-based techniques for the assessment of eccentric knee flexor strength.

**REFERENCES**