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Measuring eccentric hip adductor strength during the Copenhagen adduction exercise: A proof-of-concept and test re-test reliability study

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ABSTRACT

Objectives: To describe a novel method for measuring eccentric hip adductor (EHAD) strength during the Copenhagen adduction exercise (CAE) and investigate the test re-test reliability of this measure.
Design: Test re-test reliability study.
Participants: Twenty male athletes aged 24 ± 6 years participated in two data collection sessions 7 ± 2 days apart.
Main outcome measures: During each data collection session, participants performed three maximal effort repetitions of the CAE with their leg supported by an ankle strap hung from a fixed barbell. We attached a commercially available load cell in-series with the ankle strap to measure peak force in Newtons (N) during the eccentric lowering phase of the CAE. The intraclass correlation coefficient (ICC), standard error of measurement (SEM), SEM as a percentage of the mean (SEM%) and minimal detectable change at a 95% confidence interval (MDC_{95}) were calculated for this measure of EHAD strength.
Results: Test re-test reliability was good for EHAD strength measured during the CAE on dominant (ICC = 0.84; SEM% = 3.6%; MDC_{95} = 33 N) and non-dominant (ICC = 0.87; SEM% = 3.3%; MDC_{95} = 29 N) legs.
Conclusions: This study provides proof-of-concept that EHAD strength can be measured during the CAE with good test re-test reliability.

1. Introduction

Adductor-related groin pain is common in multi-directional field-based team sports, especially for male athletes competing in soccer, Gaelic football and hurling (Carolan et al., 2022; Hardaker et al., 2024; Mosler et al., 2018). Prevention and rehabilitation of adductor-related groin pain can be informed by measures of eccentric hip adductor (EHAD) strength (Alsirhani et al., 2024; Serner et al., 2021; Thorborg et al., 2014; Tyler et al., 2001). As with any outcome measure, the method for measuring EHAD strength should have good test re-test reliability in the population being tested. Although hand-held dynamometry (HHD) has been widely used to measure EHAD strength in male athletes competing in multi-directional field-based team sports (Alsirhani et al., 2024; Breen et al., 2021; Harøy et al., 2017; Mosler et al., 2017; Polglass et al., 2019; Serner et al., 2021; Thorborg et al., 2011, 2014; Tyler et al., 2001), test re-test reliability of this method has not been clearly established in this population.

Most studies that have used HHD to measure EHAD strength in male athletes refer to this method as being reliable by citing data collected from non-athletes, including recreationally active men (Mosler et al., 2017; Serner et al., 2021; Thorborg et al., 2011, 2014), or clinical populations (Bohannon, 1986; Marino et al., 1982; Wadsworth et al., 1987). To our knowledge, only one study has reported the test re-test reliability of HHD as a measure of EHAD strength in male athletes, which found that this method was just moderately reliable (Breen et al., 2021). Male athletes typically produce more than 250 N of peak force during EHAD strength tests (Breen et al., 2021; Harøy et al., 2017; Ishøi et al., 2016; Polglass et al., 2019), which exceeds the threshold above which HHD underestimates true strength (Beck et al., 1999; Visser et al., 2003). There appears to be a need to investigate alternative methods to HHD that may be more capable of reliably measuring EHAD strength in male athletes.

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Externally-fixed load cells have been used to reliably measure peak forces above 250 N during the eccentric lowering phase of the Nordic hamstring exercise in male athletes (Opar et al., 2013). This method could be adapted to the Copenhagen adduction exercise (CAE); an evidence-based intervention for prevention and rehabilitation of adductor-related groin pain in male athletes (Alsirhani et al., 2024; Harøy et al., 2019). An externally-fixed load cell could be used to measure EHAD strength during the eccentric lowering phase of the CAE, which involves a high-intensity hip adductor muscle contraction (Serner et al., 2014). However, this potential method for measuring EHAD strength during the CAE has not been described and the test re-test reliability of any such outcome measure would need to be established in a relevant population. This study aimed to describe a novel method for measuring EHAD strength during the CAE and to investigate the test re-test reliability of this measure in male athletes competing in multi-directional field-based team sports.

2. Methods

2.1. Participants

We recruited a convenience sample of 20 male athletes aged 24 ± 6 years, currently training and competing in a multi-directional field-based team sport, who provided their informed written consent to participate in this study. Participants were recruited either from a professional League of Ireland First Division soccer team (n = 7), or a senior Gaelic football (n = 7) or hurling (n = 6) team. All participants were free from any current injury and familiar with performing the CAE as part of their regular training.

2.2. Procedures

All study procedures were approved by the Maynooth University Biomedical and Life Sciences Research Ethics Sub-Committee (Ethics Review ID: 36459). Participants completed separate test and re-test data collection sessions 7 ± 2 days apart. We attached ankle straps to either end of a commercially available load cell (Tindeq Progressor, Trondheim, Norway), which can measure peak forces above 250 N with excellent test re-test reliability (Labott et al., 2022; Merry et al., 2021). This load cell was then externally-fixed via one of the ankle straps to a barbell positioned in a squat rack, with the other ankle strap hanging in-series (Fig. 1).

Participants had their leg positioned in the ankle strap hanging in-series with the load cell to perform the CAE for two warm-up repetitions at 50% and 75% of their perceived maximal effort and three maximal effort repetitions. Each repetition of the CAE included a 3 s concentric lifting phase and 3 s eccentric lowering phase (Ishøi et al., 2016) (Fig. 2 and Supplementary Video).

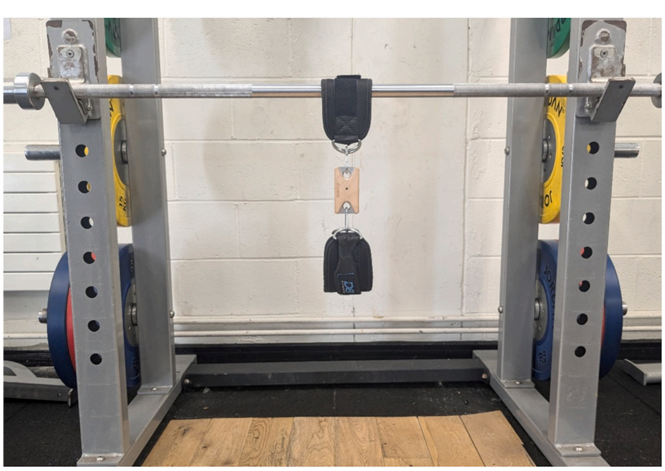

Fig. 1. Load cell externally-fixed to a barbell with ankle straps attached in-series.

2.3. Data analysis

Force-time data were collected using a freely available mobile phone application from the load cell (Tindeq Progressor, Trondheim, Norway) via Bluetooth at a sample rate of 80 Hz during each maximal effort CAE repetition. This data was exported in .csv file format to a laptop computer for subsequent analysis using custom-written code in the R programming language. The peak force value (N) measured during the 3 s lowering phase of each maximal effort CAE repetition was recorded as the measure of EHAD strength. The eccentric lowering phase of the CAE was defined as the final 3 s period of each repetition before force dropped below 200 N, which was deemed appropriate following visual inspection of force-time plots for each repetition (Fig. 3).

2.4. Statistical analysis

All statistical analysis was performed in the R programming language. Normal distribution of EHAD strength measured during the CAE was confirmed using Shapiro-Wilk's test. Paired t-tests were used to compare EHAD strength measured during the CAE between the dominant and non-dominant leg of participants, with p-values <0.05 indicating statistical significance. The intraclass correlation coefficient (ICC) with 95% confidence intervals were calculated from a two-way random-effects model for absolute agreement between single measures of EHAD strength during the CAE repetition with the highest peak force value from test and re-test sessions, respectively. These ICC values were interpreted as being excellent $\geq 0.9 <$ good $\geq 0.75 <$ moderate $\geq 0.5 <$ poor (Koo & Li, 2016). The standard error of measurement (SEM) was calculated in absolute terms as the pooled standard deviation * $\sqrt{(1\text{-ICC})}$, as well as a percentage of the pooled mean (SEM%). The minimal detectable change at a 95% confidence interval (MDC_{95}) was calculated in absolute terms as the SEM * 1.96 * $\sqrt{(2)}$, as well as in relative terms as a percentage of the pooled mean (MDC%).

3. Results

There were no statistically significant differences ($p > 0.05$) between the dominant and non-dominant legs of participants for EHAD strength measured during the CAE in the test or re-test data collection sessions (Fig. 4).

Test re-test reliability was good for measuring EHAD strength during the CAE on the dominant and non-dominant legs of participants (Table).

4. Discussion

In this study, we have described a novel method for measuring EHAD strength during the CAE and investigated the test re-test reliability of this measure in male athletes competing in a multi-directional field-based team sport. This study provides proof-of-concept that EHAD strength can be measured during the CAE with good test re-test reliability in a population that this measure is most relevant to. Our findings compare favourably to a previous study measuring EHAD strength in male rugby players, which found HHD was only moderately reliable, with ICC values of 0.62 and 0.60 on the dominant and non-dominant leg, respectively (Breen et al., 2021). This previous study also reported peak force values in the range of ~280–300 N during EHAD strength tests using HHD (Breen et al., 2021), which is ~10% less than the average peak force measured during the CAE in our study. Although direct comparison to HHD in the same cohort of participants is required, the novel method described in our study appears to provide a relatively reliable measure of EHAD strength during the CAE.

In addition to having good test re-test reliability, measures of EHAD

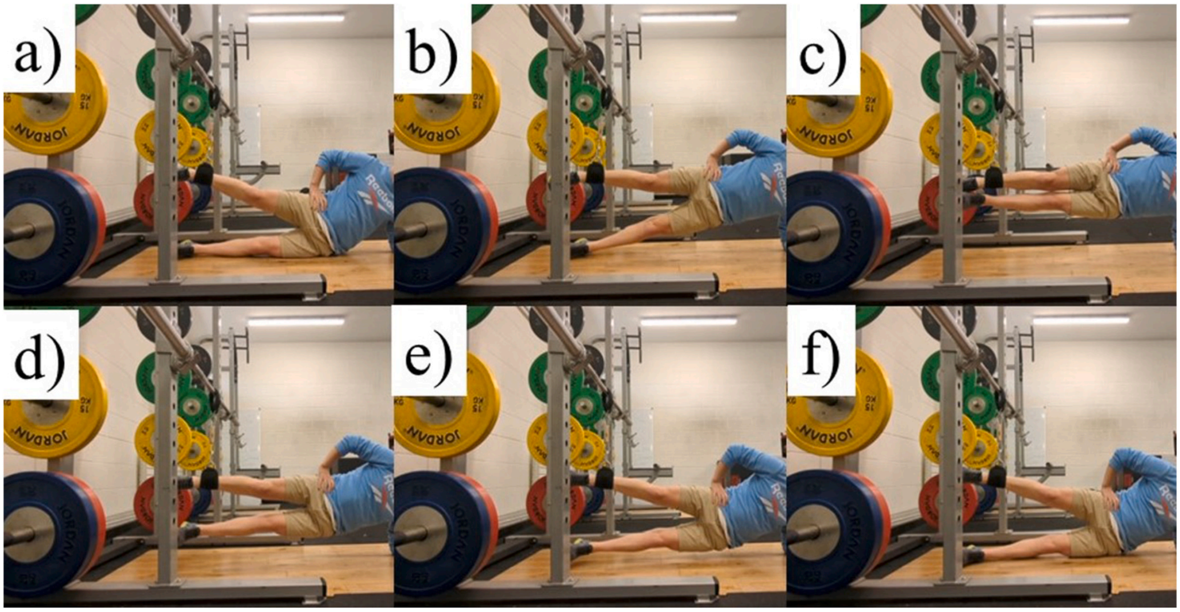

Fig. 2. Copenhagen adduction exercise starting position (a), concentric lifting phase (b–c), eccentric lowering phase (d–e) and finishing position (f).

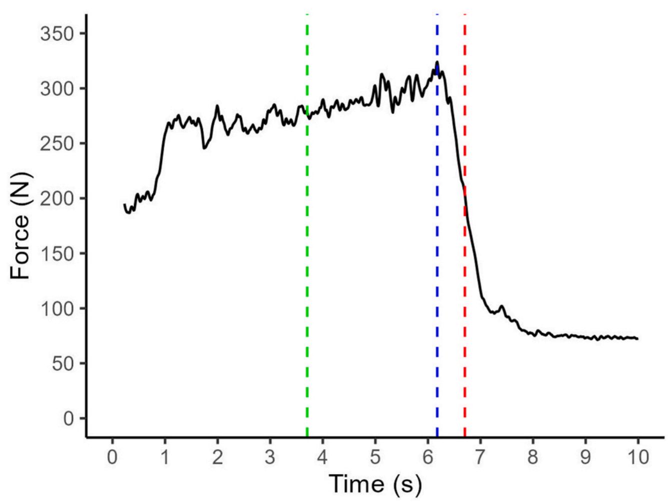

Fig. 3. Example plot showing force (y-axis) measured over time (x-axis) during a maximal effort Copenhagen adduction exercise repetition, with the timing of peak force (blue dotted line) and 3 s eccentric lowering phase highlighted from start (green dotted line) to finish (red dotted line). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

strength during the CAE were similar between the dominant and non-dominant legs of participants in our study. These findings are consistent with previous studies, which have also shown that leg dominance has no impact on EHAD strength in uninjured male athletes (Breen et al., 2021; Mosler et al., 2017). There is evidence that between-leg deficits in EHAD strength observed in male athletes with acute adductor muscle strain injuries can inform rehabilitation and return to sport decision-making (Alsirhani et al., 2024; Serner et al., 2021). Based on the MDC% of 9–10% between-sessions in our study, measures of EHAD strength during the CAE should be able detect changes in EHAD strength from the start to end of acute adductor muscle strain injury rehabilitation, which are typically much larger (Serner et al., 2021). Measuring EHAD strength during the CAE also appears to replicate lower limb kinematics of common mechanisms of acute adductor muscle strain injury in male athletes (Serner et al., 2019). Therefore, the further investigation into the validity of measuring EHAD strength during the CAE in the context of injury prevention and rehabilitation appears to be warranted.

Apart from providing a novel measure of EHAD strength, the experimental set-up described in this study could provide athletes with objective feedback when performing the CAE for injury prevention and rehabilitation purposes. Providing athletes with objective feedback when performing the Nordic hamstring exercise on a field-based testing device instrumented with externally-fixed load cells has been shown to increase force output (Chalker et al., 2018). Performing the Nordic hamstring exercise with greater force output can increase positive adaptations to this evidence-based injury prevention intervention (Pollard et al., 2019). The potential for improving performance of the CAE by providing objective feedback to athletes using the experimental set-up described in this study should be explored.

The experimental set-up described in this study uses relatively inexpensive and accessible equipment. We used a load cell that is commercially available to purchase for ~€150, which is ~90% cheaper than the HHD used to measure EHAD strength in previously published studies (Breen et al., 2021; Mosler et al., 2017; Thorborg et al., 2014). The two ankle straps can be purchased for ~€20 and the only other equipment (i.e., barbell and squat rack) is freely available in most gym environments. Apart from using relatively low cost and accessible equipment, the experimental set-up described in this study can also be implemented independent of tester strength or skill. As a result, we believe this novel method for measuring EHAD strength during the CAE reduces barriers to implementing objective testing in practice for a wider range of practitioners.

We acknowledge that our study has limitations. Participation was limited to a convenience sample of 20 male athletes competing in a multi-directional field-based team sport. We took a pragmatic approach to recruiting this convenience sample of 20 participants due to limited time available for further recruitment and data collection. Although we did not calculate adequate sample size a priori, post-hoc calculations show we had at least 80% statistical power to detect an ICC >0.5, which is the threshold for moderate reliability (Koo & Li, 2016). Although EHAD strength is most relevant to male athletes at increased risk of adductor-related groin pain, we acknowledge that this measure may still be used in other populations (e.g., female athletes), who should be included in future investigations using the method described in this study. Our discussion comparing this novel method for measuring EHAD

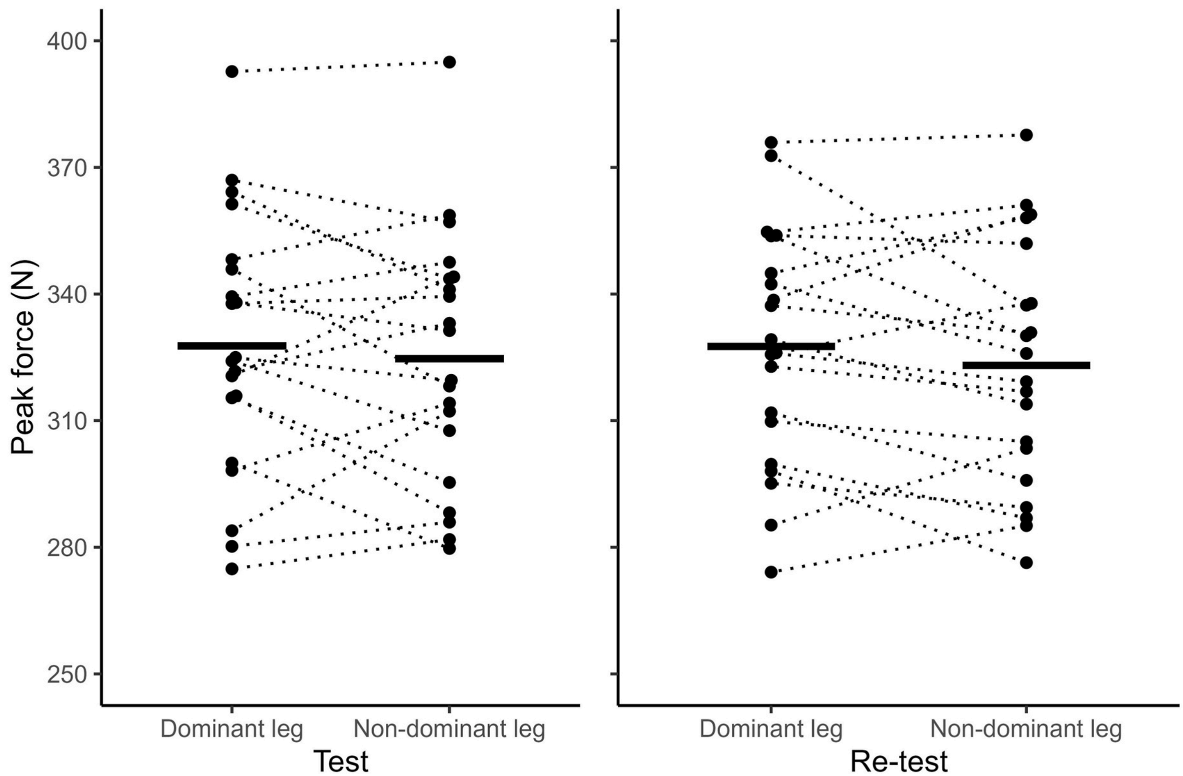

Fig. 4. Peak force measured in Newtons (N) during the eccentric lowering phase of the Copenhagen adduction exercise on the dominant leg and non-dominant leg of participants in test and re-test data collection sessions. The dotted lines connect each participant's dominant and non-dominant leg.

Table
Dominant and non-dominant leg eccentric hip adductor strength mean and standard deviation (SD) during test and re-test data collection sessions, intraclass correlation coefficient (ICC) with 95% confidence intervals (95% CI), standard error of measurement (SEM), SEM as a percentage of the pooled mean (SEM%), minimal detectable change at a 95% confidence interval (MDC_{95}) and MDC as a percentage of the pooled mean (MDC%).

Leg	Test mean (SD)	Re-test mean (SD)	ICC (95% CI)	SEM	SEM%	MDC_{95}	MDC%
Dominant	328 N (31 N)	328 N (28 N)	0.84 (0.63–0.93)	12 N	3.6%	33 N	10%
Non-dominant	325 N (30 N)	323 N (29 N)	0.87 (0.71–0.95)	11 N	3.3%	29 N	9%

strength during the CAE to previous studies using HHD is limited in the absence of direct comparison between these methods in same cohort of participants, which we encourage in future studies. Although the experimental set-up described in this study uses relatively inexpensive and accessible equipment, we acknowledge that some practitioners or athletes may not have access to a gym with a barbell and squat rack, which we used to hang the load cell from.

5. Conclusion

The novel method for measuring EHAD strength during the CAE described in this study has good test re-test reliability in male athletes competing in a multi-directional field-based team sport. This method uses relatively affordable and widely accessible equipment, which can be easily set-up in a normal gym environment to measure EHAD strength independent of tester strength or skill. We encourage further research into the reliability and validity of this novel method for measuring EHAD strength in the context of injury prevention and rehabilitation, following the initial findings of this proof-of-concept and test re-test reliability study.

CRediT authorship contribution statement

Jack T. Hickey: Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Cian Lennon:** Writing – review & editing, Writing – original draft, Project administration, Investigation, Data curation. **Michael Gillick:** Writing – review & editing, Writing – original draft, Project administration, Investigation. **Liam Sweeney:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Data curation.

Ethical statement

All study procedures were approved by the Maynooth University Biomedical and Life Sciences Research Ethics Sub-Committee (Ethics Review ID: 36459). All participants provided their informed written consent prior to participating in in this study.

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Declaration of competing interest

We, the authors, declare that we have no financial, personal or any other conflicts of interest relevant to the content of this manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2025.03.001.

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