The influence of isokinetic dynamometer configuration on eccentric hamstring strength metrics: Implications for testing and training

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Abstract

Isokinetic dynamometry is the clinical gold standard for strength assessment but testing protocols and outcome metrics can lack functional relevance. To quantify the influence of dynamometer configuration on eccentric hamstring strength metrics, 23 trained participants completed isokinetic eccentric knee flexor trials at $180^{\circ}\cdot s^{-1}$ in a seated and extended hip position. The extended position elicited greater peak torque ($P=0.04$) which was achieved at a significantly ($P<0.001$) greater degree of knee flexion. Isokinetic range and functional range (defined as 85% of peak torque) were consistent at ~44° and ~21° respectively across trials, but were achieved with a more flexed knee in the extended hip configuration. Therefore, whilst the extended hip configuration might better reflect the bi-articular nature of the hamstring musculature and the mechanism of hamstring strain injury, the sensitivity of strength metrics to configuration has implications for clinical assessment and training adaptations.

Introduction

Hamstring strain injuries (HSIs) are the most common non-contact injury in many running-based sports (Cross et al., 2015; Presland et al., 2018). High-speed running as a primary mechanism of HSI (Heiderscheit et al., 2010) reflects the biarticular functional role of the hamstrings in controlling hip flexion and knee extension (Guex and Millet, 2013). Eccentric hamstring strength in a lengthened state is subsequently highlighted as a primary and modifiable aetiological risk factor for HSI (Schmitt et al., 2012). The wealth of knowledge on HSI mechanism and aetiology should inform clinical screening, however the gold standard measurement of eccentric hamstring strength using an isokinetic dynamometer (Guex et al., 2016; Eustace et al., 2018) arguably lacks functional relevance (Greig, 2008). Isokinetic eccentric hamstring testing is traditionally conducted with the athlete in a seated position with 70-90º hip flexion and the knee at 90º resisting full knee extension (Guex et al., 2012; Ruas et al., 2018). This experimental set-up negates the biarticular function of the hamstrings and it has been proposed that a position of extended hip flexion from the torso and increased hip flexion from the involved femur would facilitate a more functional representation of the typical HSI mechanism (Thelen et al., 2005; Guex et al., 2012; Schmitt et al., 2012).

Functional specificity is also likely to be important in (p)rehabilitation and strength training. Eccentric hamstring strength training is commonly performed with the intention of reducing the risk of first-time and recurrent HSI (Askling et al., 2003; Croisier et al., 2008; Guex et al., 2012; Van der Horst et al., 2015) with positive adaptations in muscle strength (Seger and Thorstensson, 2005), flexibility (Nelson, 2006), and a shift in the angle of peak torque (APT) toward longer muscle lengths (Askling et al., 2003; Aquino et al., 2010; Brughelli et al., 2010; Guex et al., 2012). Training adaptations are likely to be specific to the exercise task, and thus dynamometer set-up has the potential to influence hamstring strength assessment and exercise prescription.

The aim of the present study is therefore to compare the traditional seated IKD position with a more functional position achieved by trunk extension and hip flexion**.** Dependent variables will be defined to include the traditional outcome measures of peak torque and the corresponding angle. More contemporary metrics will also be quantified, including functional range defined as the angular displacement over which an athlete can retain 85% of their peak torque (Eustace et al., 2017), and therefore providing broader consideration of the strength curve beyond the singular peak value. A main effect for IKD set-up would have practical implications for informing clinical choice and interpretation in testing, and for informing training interventions.

Methods

Participants

The study was completed by 23 recreationally trained participants (16 male, 7 female, 25.8 ± 6.2 years) engaged in resistance training whilst reflecting a non-sport-specific cohort. Inclusion criteria required that participants had a training status of at least 3 resistance training sessions per week, a minimum of 3 years prior experience in resistance training and were free from any soft tissue or orthopaedic injuries to the trunk, hips and lower limbs at the time of testing (Abdel-Aziem et al., 2018; Bourne et al., 2017). Exclusion criteria additionally required no prior hamstring strain injury in the last 3-months (Árnason et al., 2014) and no previous anterior cruciate ligament or any other knee injury that would preclude them from participation (Bourne et al., 2017; Ruas et al., 2018). Written informed consent was obtained prior to testing from all participants, with institutional ethical approval from the host Departmental Research Ethics Committee and in accordance with the Helsinki declaration.

Experimental Design

Participants attended the same Musculoskeletal laboratory on two occasions: a familiarisation session, and a testing session, separated by 7 days. Participants were instructed to refrain from physical activity 48-hours prior to the testing session (Ruas et al., 2018). The 7-day separation post-familiarisation allowed each participant to fit the testing into their regular periodised training week. All participants completed familiarisation trials on the IKD (System 4, Biodex Medical Systems, Shirley, New York, USA) in the two testing positions to reduce any learning effects. Familiarisation repetitions were completed initially at a speed of $60^{o}\cdot s^{-1}$ to gain habituation with the dynamometer, and subsequently at the testing speed of $180^{o}\cdot s^{-1}$. Whilst eccentric knee flexor strength is not sensitive to isokinetic speed (Abdel-Aziem et al., 2018;

Eustace et al., 2017; Guex et al., 2012; Guex et al., 2016), a speed of $180^{\circ}\cdot s^{-1}$ has been shown to elicit a dynamic control ratio of 1.0, and equivalence between concentric knee extensor and eccentric knee flexor torque (Eustace et al., 2017). The familiarisation and testing sessions were consistent in the use of a standardised warm-up specific to the task and including familiarisation repetitions within a progressive warm-up.

Each participant completed experimental trials in two dynamometer configurations: Seated, defined as: 85° hip flexion and 90° knee flexion; and Extended, defined as 65° hip flexion and 90° knee flexion measured using a goniometer. These positions are shown in Figure 1, and experimental trials were completed in randomised order.

Figure 1. The traditional and extended set-up for isokinetic hamstring assessment.

In each configuration the participant completed five maximal repetitions of eccentric knee flexion at a speed of $180^{\circ}\cdot s^{-1}$ (Eustace et al., 2017). Each maximal repetition was interspersed by a passive concentric knee flexion repetition at $60^{\circ}\cdot s^{-1}$, designed to return the dynamometer crank arm to the starting position and requiring no effort by the participant. A 10-minute rest period was given between positions to minimise the effect of fatigue (Guex et al., 2012) and to reconfigure the new testing position. In each testing position restraints were used to minimise contribution from the non-testing limbs including the contralateral leg and the trunk. All testing was performed on the participants dominant leg, defined as their preferred hopping leg.

Data Analysis

For each participant, and in each dynamometer configuration, the peak eccentric knee flexor torque for each of the five repetitions was established. The repetition eliciting the greatest peak torque was selected for subsequent analysis. The predetermined testing speed was used to define the isokinetic range, with all subsequent analysis restricted to this angular range. Dependent variables were defined as the magnitude of peak torque PT (corrected for limb weight), the corresponding angle of peak torque, and the functional range over which 0.85PT was maintained. The start and finish angles for isokinetic range and functional range were also recorded.

A univariate, repeated measures general linear model was used to quantify the main effect for dynamometer configuration in each dependent variable, with partial eta squared (η^2) reported as a measure of effect size. Statistical significance was established at $P \leq 0.05$, with all data reported as the mean ± standard deviation (SD).

Results

Figure 2 summarises the influence of dynamometer configuration on peak torque metrics. There was a significant main effect for peak torque ($P = 0.043$, $\eta^2 = 0.100$). The extended position (164.30 ± 52.34 Nm) elicited a significantly greater magnitude of peak torque than the seated position (134.82 ± 34.83 Nm). There was also a significant main effect for the corresponding angle of peak torque ($P < 0.001$, $\eta^2 = 0.328$). Peak torque was achieved at a significantly greater degree of knee flexion in the extended position (64.01 ± 8.44º) than the seated position (48.03 ± 14.77º).

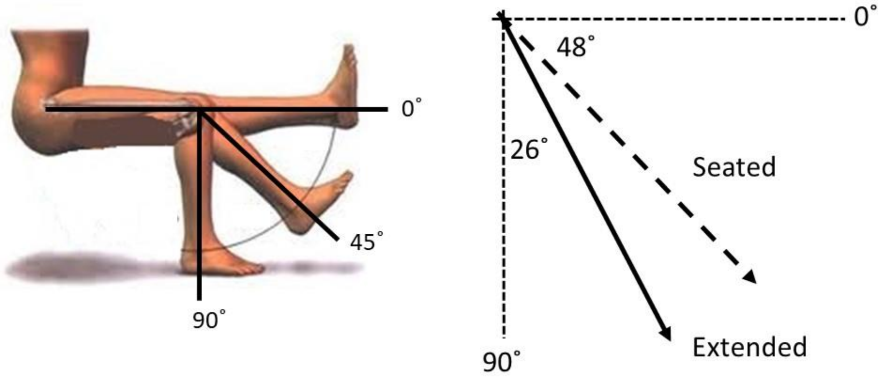

Figure 2. The influence of dynamometer set-up on Angle of Peak Torque.

There was no significant main effect for functional range (P = 0.465, $\eta^2 = 0.014$) between the extended position (22.67 ± 11.55º) and the seated position (20.04 ± 11.15º). However, Figure 3 shows how the location of the functional range differed between trials. The threshold of 85% Peak Torque was initially achieved in a significantly (P = 0.002, $\eta^2 = 0.215$) more flexed knee angle in the extended position (78.65 ± 8.83º) compared with the seated position (68.41 ± 11.23º). Whilst not significantly different (P = 0.096, $\eta^2 = 0.070$) the 85% threshold was subsequently lost at a more flexed knee in the extended position (55.83 ± 10.54º) relative to the seated position (48.03 ± 18.18º).

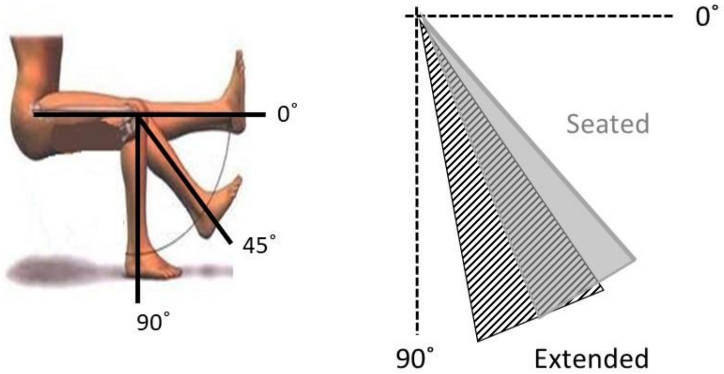

Figure 3. The influence of dynamometer set-up on Functional range.

There was no significant main effect for isokinetic range (P = 0.411, $\eta^2 = 0.017$) between the seated position (45.03 ± 10.20º) and the extended position (42.04 ± 12.46º). However, there was a significant main effect for the isokinetic range start angle (P = 0.011, $\eta^2 = 0.156$) and finish angle (P < 0.001, $\eta^2 = 0.268$). The extended position elicited an isokinetic range from 85.42 ± 6.76º to 43.38 ± 7.57º. In comparison, the seated position elicited an isokinetic range from 79.35 ± 7.74º to 34.39 ± 7.64º.

Discussion

The aim of the present study was to assess the influence of isokinetic dynamometer set-up on eccentric hamstring strength metrics, with potential implications for testing and training. With a lack of eccentric hamstring strength commonly identified as an aetiological risk factor for HSI (Schmitt et al., 2012), PT is the most commonly reported outcome measure. PT was shown to be influenced by dynamometer set-up, with a significantly greater magnitude produced in the extended hamstring position. This supports the observations of Kellis et al. (2019) who reported that 60º hip flexion elicited greater PT than 120º hip flexion at speeds of $30^{o}\cdot s^{-1}$ and $240^{o}\cdot s^{-1}$. In contrast, Guex et al. (2012) reported an increase in PT from 0º hip flexion to 90º hip flexion at $60^{o}\cdot s^{-1}$ and $150^{o}\cdot s^{-1}$. Direct comparisons should be treated with caution given differences in experimental design including isokinetic speed and participant set-up. In the previous literature the traditional seated position was employed, with only hip flexion modified such that both legs remained in a seated position. In the present study the extended hamstring position makes alterations to the hip angle but also the position of the test limb whereby the femur of the involved limb was flexed more so than the uninvolved limb to create different angular positions from the hips (Figure 1).

The greater eccentric knee flexor peak torque achieved in this extended position, and the sensitivity of PT to experimental set-up has clinical relevance when assessing the effects of a hamstring strengthening or rehabilitation programme. The novel extended set-up with a bilateral difference in hip angle allows for a varied testing position closer to the mechanism of HSI, and does elicit an increased PT and an advantageous mechanical position to elicit maximal torque generation.

The APT was also influenced by to IKD set-up, with the extended position eliciting the greater PT at a greater degree of knee flexion. The observation of greater PT elicited in a more flexed knee angle has implications in screening and training (Timmins et al., 2016) as HSI tends to occur with a more extended knee (Thelen et al., 2005). This might reflect the testing speed used in the present study, with Eustace et al. (2018) highlighting that the APT shifts toward a more extended knee as the testing speed increases. The participant demographic might also explain this observation, with these being non-sport specific and only recreationally trained. Eccentric training exposure has been shown to shift the optimum angle of peak torque in the direction of longer muscle lengths (Askling et al., 2003; Aquino et al., 2010; Brughelli et al., 2010; Guex et al., 2012), and thus the relative training status and history of this cohort might explain the PT achieved in a more flexed position. However, the observation has implications for the prescription of eccentric hamstring training, given the demand on eccentric hamstring strength towards end range to reflect the demands of high-speed running. Thus whilst the extended position might elicit a higher PT, the location of this peak strength towards knee flexion might not present the desired outcome. HSI's are often located close to the musculotendinous junction or around an intramuscular tendon (Järvinen et al., 2000) and thus end range strength is advocated for injury prevention.

The observations in the peak of the strength curve were substantiated by the functional range metric, which provides a broader perspective of the strength curve. Whilst there was no difference in the magnitude of functional range between dynamometer configurations, the extended position elicited the functional range away from knee extension. The functional range metric identifies the range over which the athlete is able to retain 85% of their PT, consistent with the definition adopted by Eustace et al. (2017) and reflecting the observations of Croisier et al. (2008) that a 15% reduction in eccentric hamstring strength increases the risk of injury. This whilst the angular range was consistent, the extended position would elicit a strength training adaptation away from the desired end range, or knee extension (Schmitt et al., 2012). Eccentric hamstring strength might therefore be developed in the less functional phase of the movement, relative to the running injury mechanism. Conversely, where an athlete is compromised in that range, or that range has specific performance benefits, the extended position presents a unique and specific challenge.

The angular position at which strength is assessed and developed has important clinical and training implications, but also of note is the relatively limited isokinetic range, which inevitably is reduced further as isokinetic speed is increased. A lower speed, arguably offering less functional relevance, might elicit a similar PT given the lack of sensitivity of PT to test speed

(Abdel-Aziem et al., 2018; Eustace et al., 2017; Guex et al., 2012; Guex et al., 2016; Kellis et al., 2019), but provide a greater angular displacement over which peak torque can be assessed. The higher testing speeds reduce the isokinetic range and in the current study no isokinetic data was obtained beyond 35º of knee flexion. Therefore, to test end range strength, and facilitate greater functional relevance to the mechanism of HSI, either a very slow isokinetic speed is required or isometric testing should be used to supplement the isokinetic test(s). Previous studies have shown that testing isometrically elicits a lower PT compared to eccentric contractions (Guex et al., 2012), with implications for development of strength in rehabilitation. Therefore, a hybrid protocol comprising functionally relevant isokinetic speed(s) and functionally relevant isometric joint angle(s) might be advocated for both assessment and exercise prescription, acknowledging that time restrictions in a clinical context might impact the transferability of this proposal**.** Eccentric resistance training programmes elicit superior neuromuscular adaptations compared to both isolated concentric training and traditional resistance training exercises (Roig et al., 2009) and promote a shift in the angle of peak torque towards a more extended position (Brughelli et al., 2010; Guex et al., 2016) and longer muscle lengths (Bourne et al., 2017). Additional eccentric training adaptations have been observed in increased hamstring flexibility (Nelson, 2006) and fascicle length (Bourne et al., 2017). Heavier eccentric training loads have been shown to facilitate greatest gains in eccentric strength (English et al., 2014), with implications for the extended position. Furthermore, greater eccentric strength gains are associated with fast eccentric training (Farthing and Chilibeck, 2003), particularly when speed reflects the demands of an athlete's training regime (Roig et al., 2009).

Care should be taken when generalising the findings of the current study beyond the specific participant demographic and isokinetic design elements. The participants included male and female athletes who were not sport-specific and only recreationally trained, and thus their capacity to develop eccentric hamstring strength towards end range might reflect a lack of exposure to high-speed running. Isokinetic dynamometer configuration is at the discretion of the practitioner, as is the testing velocity. Future research might consider more variation of the eccentric knee flexor set-up to consider the optimum position to reflect the biarticular function of the hamstrings, and a prone position which more closely replicates the traditional hamstring curl exercise for recreational athletes. The sensitivity of the outcome metrics to isokinetic speed, particularly given the influence on isokinetic range warrants consideration. It must also be acknowledged that the measurement of net joint torque negates the opportunity to explore the implications on the hamstring musculature, with biceps femoris the most commonly injured injuries (Ekstrand et al., 2011; Presland et al., 2018). The extended hamstring configuration does offer the advantage of facilitating electromyographical analysis of the hamstring musculature.

Conclusion

The aims of the study were to assess the effect of IKD set-up on eccentric hamstring strength metrics in a recreationally trained cohort, with practical implications in testing and training. Whilst the extended hamstring position did elicit an increased peak torque, the angle of peak torque and the functional range were located closer to knee flexion, and thus potentially lacking functional relevance to the mechanism of injury and the aetiological risk factor of eccentric hamstring length in a lengthened state.

Disclosure Statement

No conflicts of interest to report.

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