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ABSTRACT

The Nordic Hamstring Exercise (NHE) has been introduced as a training tool to improve the efficiency of eccentric hamstring muscle contraction. The aim of this study was to perform a biomechanical analysis of the NHE. Eighteen participants (20.4 ± 1.9 years) performed two sets of five repetitions each of the NHE and maximal eccentric voluntary contraction (MEVC) of the knee flexors on an isokinetic dynamometer whilst knee angular displacement and electrical activity (EMG) of biceps femoris were measured. EMG was on average higher during the NHE (134.3% of the MEVC). During the forward fall of the NHE, the angle at which a sharp increase in downward velocity occurred varied between 47.9 and 80.5 deg, while the peak knee angular velocity (pVelocity) varied between 47.7 and 132.8 deg s^{-1}. A significant negative correlation was found between pVelocity and peak EMG ($r = -0.62$, $p < 0.01$) and EMG at 45 deg ($r = -0.75$, $p < 0.01$) expressed as a percentage of peak MEVC EMG. Some of the variables analyzed exhibited good to excellent levels of intra- and inter-session reliability. This type of analysis could be used to indirectly monitor the level of eccentric strength of the hamstring muscles while performing the NHE and potentially any training- or injury-related changes.

1. Introduction

Hamstring muscle and tendon injuries are prevalent in many sports with sprinting, jumping and kicking actions. A high prevalence of hamstring muscle and tendon injury recurrence has been reported in sports such as Gaelic football, Australian Rules football, soccer, rugby (Brooks et al., 2006) and athletics (Malliaropoulos et al., 2012). Over the last decades a large body of literature has been published relating to the etiology and risk factors associated with hamstring injuries and it is generally accepted that these types of injuries are multi-factorial in nature (Mendiguchia et al., 2012).

Despite the complex etiology, some efficacious strategies for injury prevention have been identified (Petersen and Holmich, 2005). The use of eccentric exercise in the prevention and rehabilitation of hamstring injuries has been advocated by numerous authors (Brockett et al., 2004; Chumanov et al., 2012; Opar et al., 2012). The rationale for the utilization of eccentric exercise in the prevention and rehabilitation of hamstring injuries relates to the time phase of running gait associated with hamstring injury (Schache et al., 2012). During the late swing phase of running gait the hamstring muscles are subjected to a high mechanical strain as they lengthen and contract eccentrically, and it is during this time phase of running gait that hamstring injuries most often occur (Chumanov et al., 2012; Petersen et al., 2011). It is believed that during a series of eccentric contractions more and more sarcomeres will become overstretched and disrupted, with one of the consequences being a shift in optimum length for tension in the direction of longer muscle lengths, eventually leading to multiple microscopic damages which can grow into an injury (Proske and Allen, 2005). One of the benefits of performing eccentric loading of the knee flexors is likely to be an increase in the physiological working length of the muscle, thus preventing sarcomeres from reaching a critical length that could make them prone to an initial microscopic damage (Iga et al., 2012).

Previous published work has documented positive effects of eccentric exercise including a reduction in hamstring muscle and tendon injury risk, improved lower limb strength and sprint ability (Askling et al., 2003). Eccentric exercise has also been used successfully for injury prevention in a case study involving an Australian Football player with recurrent hamstring injuries (Brughelli et al., 2009).

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A commonly utilized eccentric exercise is the Nordic Hamstring Exercise (NHE), whereby the ankles of a kneeling subject are secured while they slowly lower their upper body trying to break the fall by contracting their hamstring muscles. Firstly introduced in 2001 (Brockett et al., 2001), the NHE has been used in a number of papers with the aim of enhancing muscle strength and preventing injuries. In two prospective studies the addition of the NHE to the training program of professional rugby union (Brooks et al., 2006) and elite soccer players (Arnason et al., 2008) resulted in a reduction in both the incidence and severity of hamstring injuries. In two randomized controlled trials the rate of hamstring injury in soccer (Petersen et al., 2011) and Australian Rules football (Gabbe et al., 2006) players was reduced in those athletes who performed the NHE as part of a pre-season and in-season injury prevention intervention. There was a 60% and 85% reduction in new and recurrent injuries, respectively (Petersen et al., 2011), whilst Gabbe et al. (2006) reported a hamstring injury incidence of 4% in the intervention group as opposed to 13% in the control group. Interestingly, another study compared traditional hamstring curls to a NHE intervention and reported that 10 weeks of a NHE intervention is more effective in developing maximal eccentric hamstring strength (Mjølsnes et al., 2004).

On the whole, a number of previous investigations provide evidence that the NHE is effective in improving hamstring muscle strength as well as reducing the risk of hamstring injury. It has been suggested that this is because insufficient hamstring strength has been identified as a risk factor for injury and the activity of this musculature is maximized when they work eccentrically or during transition from eccentric to concentric muscle action (Arnason et al., 2008). The NHE has also been shown to cause a shift in the muscle's torque–angle curve to longer muscle lengths as a protective strategy (Brockett et al., 2001). Furthermore, the NHE is a popular training exercise commonly used by strength and conditioning coaches and physical therapists. Despite its widespread use, only one recent paper has addressed the question of the level of hamstrings activation during performance of the NHE (Iga et al., 2012), yet the authors did not present any kinematic data. Such information would allow researchers and clinicians alike to quantify and monitor the training-related adaptations to an injury prevention intervention based on the NHE. Accordingly, the aim of this study was twofold: (a) to provide a biomechanical description of the NHE by measuring angular velocity of the movement and activity of the biceps femoris (BF); (b) to assess intra- and inter-session reliability of the mechanical parameters describing the NHE.

2. Methods

2.1. Research design

After a warm up, participants were required to undertake, in random order, a NHE test and a maximal eccentric voluntary contraction (MEVC) test while the electrical activity of BF and the angular displacement of the knee joint of the right leg were monitored through surface electromyography (EMG) and an electrogoniometer, respectively. Since a previous study showed no difference in the level of muscle activation between lower limbs when the NHE was performed (Iga et al., 2012), it was decided to take measurements only from the right lower limb. The activity of BF measured during the performance of the NHE and the MEVC was compared. The NHE was performed over two testing sessions 4 weeks apart and in each session multiple movements were performed. This allowed the assessment of the intra- and inter-session reliability of the mechanical parameters used to investigate the NHE.

2.2. Subjects

Eighteen male university students (age: 20.38 ± 1.94 years; height: 177.73 ± 6.05 cm; body mass: 77.23 ± 10.42 kg) agreed to participate in this study, which was approved by the Human Research Ethics Committee of University College Dublin. All participants were involved in field sports (Gaelic football, rugby and soccer) and they had to be free from hamstring injuries within the previous 6 months prior to the study. They gave written informed consent for participation, were briefed on the aim of the study and were required to rest the day before each testing session. Fourteen participants completed the second testing session (inter-session reliability).

2.3. Testing protocol

2.3.1. Warm up

Participants warmed up by pedalling on a cycle-ergometer for 5 min at a cadence of 70–80 RPM and at a constant resistance of 100 W.

2.4. Nordic Hamstring Exercise (NHE)

The participant had to kneel on the floor with the upper body vertical and straight while a partner applied pressure to the heels in order to make sure that the feet kept contact with the floor throughout the movement. They slowly lowered their upper body trying to resist the fall by contracting the hamstring muscles. Arms were kept flexed with hands by the shoulders as long as possible and they would be pushed forward only at the final stages of the movement to buffer the fall. After thorough familiarization participants performed two sets of 5 NHE movements, with a 10 s interval between each fall, which included the time to return to the starting position, and a 2 min interval between each set. The second set of NHE movements was considered for later analysis.

2.5. Maximal eccentric voluntary contraction (MEVC)

An isokinetic dynamometer (Biodex System III, Biodex Medical System, NY, USA), sampling at 100 Hz, was used to assess the MEVC of the hamstring muscles. Participants were seated on the chair and firmly strapped to the seat with the hip flexed at 100 deg. The rotational axis of the dynamometer was aligned to the lateral femoral condyle of the right leg. The lower leg was strapped to the machine lever arm 2 cm superior to the lateral malleolus. After the dynamometer was calibrated and gravity correction was performed, participants were instructed to oppose the knee extension controlled by the machine by maximally attempting to flex the knee. The range of motion was 90 (leg vertical) to 30 deg (where 0 deg represents full extension). After thorough familiarization two sets of five repetitions were performed in random order, at 30 deg s^{-1} and verbal encouragement was provided during the repetitions. A resting period of 3 min was allowed between the two sets. The repetition with the highest electrical activity of BF was considered for later analysis.

2.6. Electromyography (EMG)

Whilst performing the NHE and the MEVC, EMG was recorded from the BF. The skin was shaved, slightly abraded with sandpaper and cleansed with alcohol and Ag/AgCl bipolar electrodes (Blue Sensor N-00-S, Ambu Medicotest A/S, Ølstykke, Denmark) were placed according to the SENIAM guidelines (Freriks et al., 1999) at an interelectrode distance of 20 mm. The surface EMG signal was amplified with a gain of 1000. Common mode rejection rate and input impedance were 110 dB and 1 MΩ, respectively. The

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raw EMG signal was online band-pass filtered using a fourth-order, Butterworth filter, with cut-off frequencies of 1 and 500 Hz.

2.7. Electrogoniometry

A single axis electrogoniometer (SG110, Biometrics Ltd., Newport, UK) was used in order to record the knee joint angle as previously reported (Chan et al., 2001). The electrogoniometer was secured across the lateral aspect of the right knee. Specifically, with the participant in a kneeling position to simulate the starting position of the NHE, one end block of the sensor was placed above the knee joint perpendicular to the floor and in line with the lateral border of the greater trochanter; the second end block was attached to the lateral side of the upper section of the shank, parallel to the floor and in line with the lateral malleolus of the ankle.

2.8. Data recording and reduction

The EMG and knee joint angle signals were synchronized, sampled at 2000 Hz, and stored on a PC using a 16 bit A/D converter data acquisition system (Biopac Systems, Inc., Goleta, CA, USA). The EMG signal was off-line high-pass filtered (fourth order, zero-lag, Butterworth filter, cut-off frequency 20 Hz), followed by the application of a moving root-mean-square filter with a time constant of 100 ms. The knee joint angle signal and the torque signal were off-line low-pass filtered using a fourth order zero-lag Butterworth filter with a cut-off frequency of 5 Hz and 15 Hz, respectively.

2.9. Variables analyzed

A typical NHE movement, with knee angular displacement and muscle activity of BF, is represented in Fig. 1. The start of the forward fall was determined as the point corresponding to the onset of BF electrical activity, the latter identified as 2 SD over the baseline, whereas the lowest value of the knee angular displacement signal was identified as the end of the fall; this gives the total range of motion (ROM, deg) of the movement. Fig. 1 allows for the identification of the peak EMG (mV) and angle (deg) at which peak EMG occurred (pEMG and angle at pEMG, respectively). The level of EMG of the BF was also recorded at 75 deg (EMG75) and 45 deg (EMG45) of the forward fall, in order to determine the muscle activation at two specific points (i.e. when the movement is still largely controlled and when an increase in angular velocity has occurred). By taking the first derivative of knee angular displacement with respect to time the angular velocity was obtained and plotted against the angular displacement (Fig. 2). The peak angular velocity (pVelocity, deg s^{-1}) was determined. In addition, the angle characterizing the end of trunk control (angle at downward acceleration, DWA) was identified as the point on the curve where a sudden increase in velocity occurred. This was computed by running a slope function over adjacent 200 ms time windows (100 ms overlap). Slope difference between one time window and the previous one were calculated. The angle (deg) corresponding to the initial point of the time window that yielded the highest slope difference was labeled angle at DWA (Fig. 2).

The following variables were considered for the MEVC: pEMG and angle at pEMG, EMG at 45 (EMG45) and 75 degrees (EMG75) of knee angle. The velocity of 30 deg s^{-1} was chosen because a pilot study revealed that at approximately this velocity pEMG of the BF occurred during the performance of the NHE (Fig. 3).

2.10. Statistical analysis

Statistical analysis was performed using Statistica version 10 (Statsoft Ltd., Bedford, UK). Results are presented as mean, standard deviation, minimum and maximum values. The variables were checked for normality of distribution using a Shapiro–Wilk

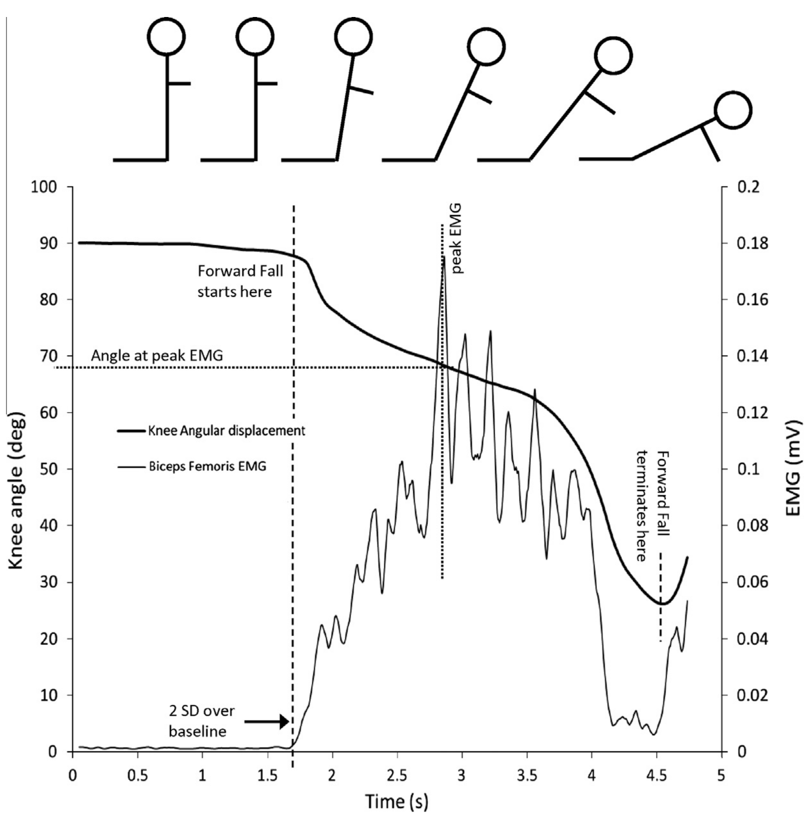

Fig. 1. Schematic representation of the Nordic Hamstring Exercise movement (top) with typical knee angular displacement and muscle activity (EMG) of Biceps Femoris traces over time. Start and end of the forward fall are indicated.

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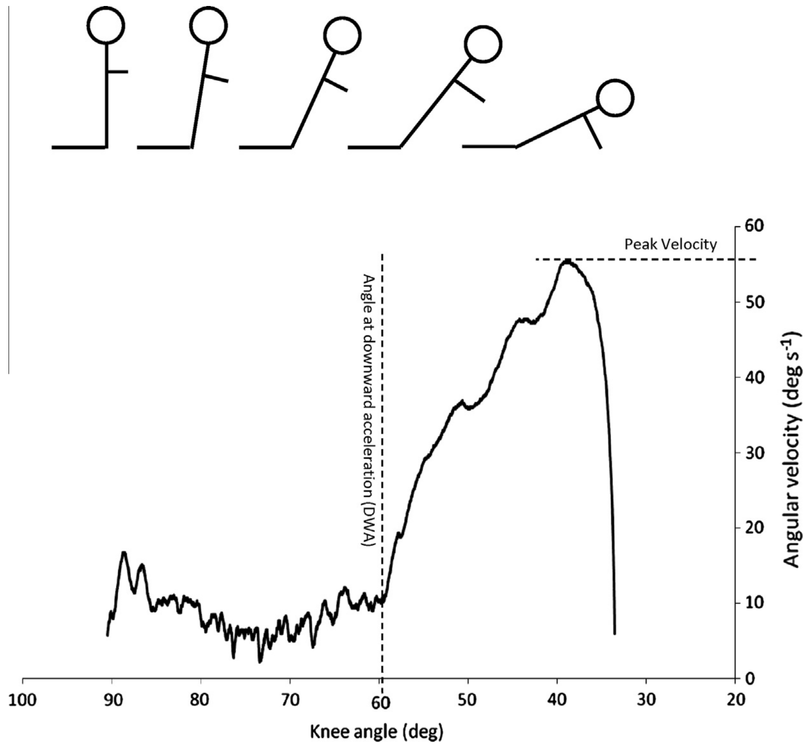

Fig. 2. Schematic representation of the Nordic Hamstring Exercise movement (top) with typical knee angular velocity trace over knee angle. The peak velocity and angle at downward acceleration are indicated.

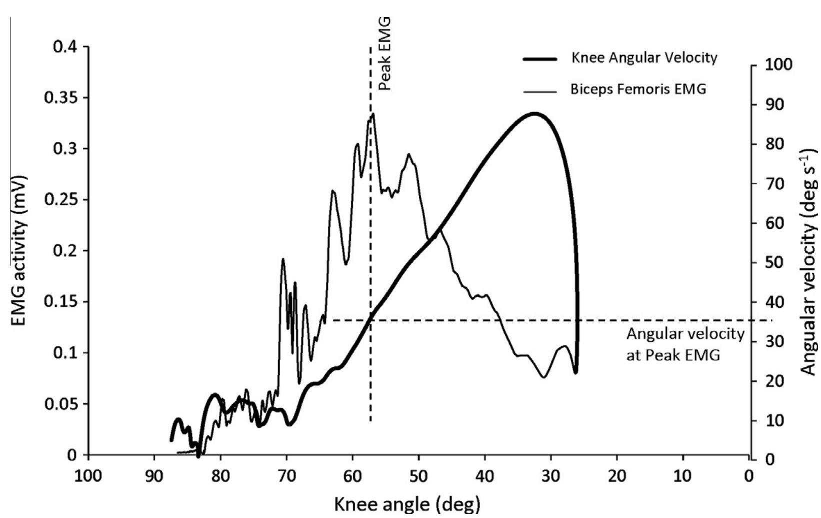

Fig. 3. Typical traces of the muscle activity (EMG) of the Biceps Femoris and knee angular velocity over knee angles. The instantaneous knee angular velocity at peak EMG is indicated.

test and log-transformed when necessary (MEVC variables). A repeated measure ANOVA was used to compare peak EMG, EMG75 and EMG45 for both NHE and MEVC followed by an LSD post hoc analysis; the angle at pEMG was compared between NHE and MEVC using a paired *t-test*. The level of BF activation obtained during the NHE was expressed as a percentage of MEVC's level as follows (%EMG):

$$\frac{EMG(NHE)}{EMG(MEVC)}100 \qquad (1)$$

A Pearson's correlation coefficient was used to relate pVelocity with the level of muscle activation taken at two points of the ROM, %pEMG and %EMG45 (on average not different from the angle at which pVelocity occurred). An alpha level of $p < 0.05$ was considered statistically significant.

In order to evaluate relative and absolute reliability of the parameters describing the NHE, intraclass correlation coefficient (ICC) and coefficient of variation (CV) were calculated, respectively. The ICC is defined as $(V - v)/V$, where V is the between-participant variance averaged over the two trials analyzed, and v is the square of the standard error of measurement (Weir, 2005). Systematic bias between the two testing sessions (inter-session reliability) was analyzed using a paired *t*-test, whereas an analysis of variance (ANOVA) with repeated measures was used to detect systematic bias between the five NHE movements (intra-session reliability) (Atkinson and Nevill, 1998).

3. Results

The results of kinematic analysis and muscle activity of BF during the performance of the NHE and the MEVC are presented in Table 1. The pVelocity showed a high inter-individual variability (between 47.7 and132.8 deg s^{-1}) with the angle at DWA being approximately after the first half (at 68.1 deg) of the total ROM (51.3 deg) and angle at pVelocity occurring towards the end of the movement (at 44.4 deg).

On average the level of EMG activity was different across the three conditions (pEMG, EMG45 and EMG75) for both NHE and MEVC ($F = 35.8$, $p < 0.01$; $F = 23.6$, $p < 0.01$; respectively) and the post hoc analysis revealed where the differences lay (Table 1). Interestingly, no significant difference was observed in the angle at pEMG between NHE and MEVC ($p = 0.29$) despite an average difference of approximately 6 deg. Although a high inter-individual difference exists, 12 out of 18 participants exhibited a higher level of pEMG during the NHE as opposed to a traditional eccentric exercise (MEVC) and on average pEMG during the NHE is 134.3% of the MEVC. The latter generated a remarkable peak torque of 160.2 ± 26.6 Nm (data not shown).

A significant negative linear correlation was found between pVelocity and %pEMG ($r = -0.62$, $p < 0.01$) or %EMG45 ($r = -0.75$, $p < 0.01$) (Fig. 4a and b, respectively) meaning that a higher level of muscle activation was generated in those participants who more effectively broke the forward fall, i.e. exhibited a lower knee angular velocity.

Table 1
Kinematic and electromyographic results of the Nordic Hamstring Exercise and the Maximal eccentric voluntary contraction.

	Mean	SD	Min	Max
NHE				
pVelocity (deg s^{-1})	81.3	23.8	47.7	132.8
Angle at DWA (deg)	68.1	8.0	47.9	80.5
pEMG (mV)*	0.312	0.130	0.071	0.509
Angle at pEMG (deg)	65.4	8.6	54.1	79.2
Total ROM (deg)	51.3	7.6	41.1	62.6
EMG at 75 deg (mV)**	0.124	0.061	0.023	0.263
EMG at 45 deg (mV)	0.158	0.094	0.027	0.326
MEVC				
pEMG (mV)§	0.276	0.146	0.106	0.619
Angle at pEMG (deg)	71.0	9.8	51.0	87.0
EMG at 75 deg (mV)§§	0.179	0.109	0.069	0.410
EMG at 45 deg (mV)	0.131	0.092	0.037	0.377
pEMG (NHE expressed as a percentage of MEVC)				
	134.3	73.1	44.5	282.4
EMG at 75 deg (NHE expressed as a percentage of MEVC)				
	95.6	70.2	40.6	206.2
EMG at 45 deg (NHE expressed as a percentage of MEVC)				
	129.9	62.4	33.9	241.1

NHE = Nordic Hamstring Exercise; MEVC = maximum eccentric voluntary contraction; *p* = peak; DWA = downward acceleration; ROM = range of motion; EMG = surface electromyography.
* significantly different from EMG at 75 deg and EMG at 45 deg ($p < 0.01$).
** significantly different from EMG at 45 deg ($p < 0.05$).
§ significantly different from EMG at 75 deg and EMG at 45 deg ($p < 0.01$).
§§ significantly different from EMG at 45 deg ($p < 0.05$).

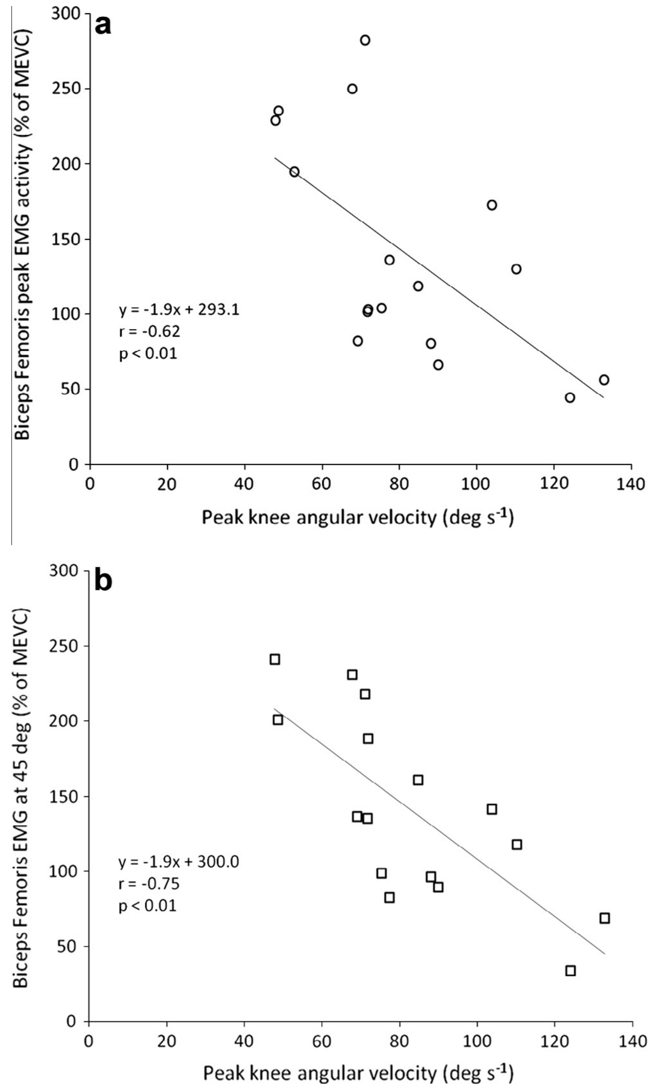

Fig. 4. Linear negative relationships between peak knee angular velocity and peak EMG activity (a) and EMG activity at 45 deg of knee angle (b) of the Biceps Femoris, expressed as a percentage of maximal eccentric voluntary contraction (MEVC) Linear regression equation is reported, along with correlation coefficient (r) and level of significant ($p < 0.01$).

Table 2
Reliability results of the Nordic Hamstring Exercise.

	Intra-session reliability		Inter-session reliability	
	ICC	CV (%)	ICC	CV (%)
pVelocity	0.91–0.96	8.25	0.94	10.32
Angle at DWA	0.94–0.97	3.78	0.95	2.82
pEMG	0.82–0.94	18.02	0.81	21.97
Angle at pEMG	0.70–0.90	9.01	0.97	5.04
Total ROM	0.91–0.98	4.68	0.88	10.58
EMG at 75 deg	0.78–0.96	21.98	0.80	29.29
EMG at 45 deg	0.72–0.97	21.99	0.81	28.72

ICC = Intraclass correlation coefficient; CV = coefficient of variation; *p* = peak; ROM = range of motion; EMG = surface electromyography.

Intra- and inter-session reliability of the parameters describing the NHE is reported in Table 2. As a general rule, the level of intra-session is higher than the inter-session reliability, except for the angle at pEMG and angle at DWA. Four variables (pVelocity, angle at DAW, angle at pEMG and total ROM) exhibit good to excellent levels of reliability. No significant systematic bias was detected for any of the variables analyzed ($p > 0.05$).

4. Discussion

This is the first study to conduct a neuro-mechanical analysis of the NHE, a popular exercise devised to eccentrically contract the hamstring muscles. The NHE is regarded as an effective training tool to specifically strengthen the knee flexor muscles (Mjølsnes et al., 2004) or to prevent injuries (Arnason et al., 2008). However, although positive results have been extensively reported, the NHE had yet to be examined in terms of muscle activation and kinematics. The level of BF activation, along with the pVelocity and angle at DWA recorded during the forward fall appear to be the most relevant parameters to appropriately describe the NHE.

The results showed that during the performance of the NHE the BF is highly activated, in fact for the majority of the participants the peak activation was higher during the NHE compared to a traditional maximal eccentric exercise performed on an isokinetic dynamometer (i.e. MEVC). It is interesting to note that the level of pEMG varies from approximately half to nearly three times the level of activation recorded during a MEVC. This high variability, although not easy to explain, may be due a natural ability of each individual to perform better at either the NHE or the MEVC. In addition, BF and the other knee flexors may have individual different relative contributions to the torque generation depending on the specific task (Iga et al., 2012; Onishi et al., 2002) whilst in this study only the activity of the long head of the BF was measured. Considering the high inter-individual differences in the engagement of the BF during the performance of the NHE, the optimal training load to be administered when the NHE is used either to strengthen the muscles or during rehabilitation sessions of previously strained hamstrings could be an interesting matter for future research.

The EMG amplitude of the eccentric contraction has been shown to be lesser than that of the concentric contraction mainly because of a reduced number of motor units recruited and a decreased discharge rate (Garner et al., 2008), despite no significant difference (Kay et al., 2000) or even a greater torque generation during the eccentric contraction (Kellis and Baltzopoulos, 1998). This may be due to the greater passive force contributions of the parallel and series elastic components during muscle lengthening and a smaller requirement for motor unit activation (Garner et al., 2008). Since both exercises examined in this study involve an eccentric contraction, it can be assumed that the elevated level of EMG amplitude during the NHE was elicited by a larger number of motor units recruited which in turn may have increased the muscle force generated. Unfortunately the NHE cannot be performed in a dynamometer, therefore it is not possible to measure – non-invasively – the force generated and this is a recognized limitation when this investigation attempts to compare the NHE to a traditional eccentric exercise. Another limitation that can be observed in this comparison arises from a mechanical analysis of the two exercises. The NHE involves fixing the distal insertion of the BF and stretching the muscle by pulling the proximal insertion when the upper body starts leaning forward. It is during the later phases of the movement that the muscles have to contract more forcefully to prevent the forward fall. In contrast, the opposite happens when the MEVC is performed on an isokinetic dynamometer because the leg is pulled away from a 90 deg position, therefore the greatest EMG amplitude occurs during the early phases of the movement. This is reflected in the EMG75 being higher for the MEVC (0.179 vs. 0.131 mV, $p < 0.05$) and the EMG45 being higher for the NHE (0.158 vs. 0.124 mV, $p < 0.05$). However, the angle at pEMG was found not to be significantly different between the two exercises, meaning that regardless of the muscle mechanics, the highest muscle activation occurs approximately at the same knee angle.

The level of reliability of the EMG parameters (pEMG, EMG75 and EMG45) of the NHE is overall low to acceptable. When looking at the inter-session reliability over a 4-week period, the ICC obtained in this study is similar if not better than that reported in a previous investigation (0.80–0.81 vs. 0.53–0.88) (Clark et al., 2007). In contrast, this study exhibited higher (i.e. worse) levels of CV (22.0–29.3 vs. 13.1–19.9%). It has to be said though that the study by Clark et al. (2007) analyzed the muscles of the leg, as opposed to analysis of the BF in this study, and the finding that different muscles show different levels of reliability is not unprecedented (e.g. Jobson et al., 2012). The level of intra-session reliability is questionable to good for this study, however it is lower than that of another investigation examining multiple contractions of the same muscle (i.e. BF) during cycling (ICC: 0.72–0.97 vs. 0.92–0.99; CV: 18.0–22.0 vs. 4.5–8.7%) (Fernández-Peña et al., 2009). Obviously cycling implies a more regular action, and possibly muscle recruitment, than the NHE; in addition the contraction intensity is likely to be different between the two studies. The strenuous contraction intensity of the BF during the NHE could be another factor that accounts for a lower intra- and inter- session reliability of the activity of this muscle when compared with other studies. Finally, a high variability of the BF EMG could be explained by different strategies used during the performance of the NHE, such as pelvis rotation or hip flexion, which can alter the intervention of the knee flexors. Although this has been minimized by familiarizing the participants with the task and by having the same experienced test administrator, the use of stereophotogrammetry could have provided a better insight into the analysis of the NHE. Unfortunately this technique could not be implemented in the present study, and this is a recognized limitation.

The angle at DWA and pVelocity are arguably the most informative parameters to be measured during the performance of the NHE. The former represents the point in time when the control of the forward fall is lost, which translates into a sudden increase in downward velocity (Fig. 2). An improvement in the NHE performance (i.e. how well the subject manages to break the forward fall), should aim at delaying the angle at DWA, which means longer control over the downward movement. If the downward acceleration is delayed the pVelocity is expected to reach lower values because the angular range of motion over which the velocity can develop is reduced. The high range of pVelocity (47.7–132.8 deg s^{-1}) and angle at DWA (47.9–80.5 deg) values recorded shows very different abilities in this specific task among the participants recruited, despite all of them being involved in team sports which require a high activation of the knee flexor muscles.

During the performance of the NHE, the gravity acceleration elicits the forward fall of the trunk and as the forward lean of the trunk increases, the greater is the magnitude of the rotational component of the gravity acceleration. In contrast, the contraction of the knee flexors opposes the movement. Previous research has shown that the intensity of hamstring contraction (in percentage of maximal voluntary contraction or exercise intensity) is proportional to the EMG amplitude in both isometric (Campy et al., 2009) and dynamic contraction (Fernández-Peña et al., 2009). In this study the more vigorous contraction of the knee flexors (i.e. the greater BF pEMG), can be interpreted as a higher ability to oppose the forward fall, thus reducing the pVelocity. The pEMG occurs earlier than pVelocity (65.4 vs. 44.4 deg) whereas EMG45 occurs approximately at the same knee angle as pVelocity (44.4 deg). When %pEMG and %EMG45 were related to pVelocity a significant negative relationship was found clearly indicating that those participants who exhibited a lower value in pVelocity were able to more forcefully contract the BF and the other knee flexor muscles, thus reducing the velocity of the forward fall.

An overall good to excellent level of intra- and inter-session reliability of these kinematic parameters was observed, which is in agreement with a recent study examining the range of motion of the knee angle during the dynamic barbell squat exercise (Brandon et al., 2011), and this encourages their use to monitor the NHE.

Even though the NHE has been devised to be performed in a gym/field environment rather than in a laboratory (Brockett et al., 2001), a kinematic and electromyographic analysis can provide a unique insight that may enable coaches and therapists to prescribe training sessions more appropriately. Simply by measuring the angular displacement at the knee it is possible to track a meaningful change in forward fall velocity which can be attributed to an improvement in eccentric muscular contraction. An intervention study is warranted to examine to what extent pVelocity and angle at DWA can be improved as a result of a specific training activity. A second and more challenging step is to ascertain whether an alleged improvement in the ability to perform the NHE translates into stronger and less prone to injury leg flexor muscles.

5. Conclusion

In this study an electromyographic and kinematic analysis of the NHE was carried out. It has been demonstrated that on average and for the majority of the participants the NHE elicited a higher level of BF activity compared to a traditional maximal eccentric exercise performed on an isokinetic machine. The analysis of the knee angular displacement vs. time showed that pVelocity and angle DWA could be used to indirectly monitor the level of eccentric strength of hamstring muscles while performing the NHE and potentially any training-related changes. The aforementioned parameters exhibited good to excellent levels of intra- and inter-session reliability.

The participants in this study were included only if they did not report any recent hamstring injuries. As such the results presented can also be seen as the first step towards the creation of a normative database of a non-injured population involved in team sports. Such a profile would allow for the potential determination of readiness of return to play following injury. Essentially this could facilitate the objectification of return to play decisions, thus allowing for the monitoring of rehabilitation progress.

Conflict of interest

The authors declare that they have no conflict of interest.

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