SPORTS BIOMECHANICS
https://doi.org/10.1080/14763141.2021.2025416

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Effects of ankle position during the Nordic Hamstring exercise on range of motion, heel contact force and hamstring muscle activation

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ABSTRACT

One of the main benefits of the Nordic Hamstring Exercise (NH_E) is that it can be performed without the need of any extra material. However, numerous technical execution variables such as the ankle and pelvis position can influence the performance. The primary aims of this study were to investigate the effects of ankle position (i.e., plantar or dorsal flexion) on Nordic Hamstring Break Point (NH_{BP}), repetition time and heel contact force. A secondary aim was to investigate differences in biceps femoris long head and semitendinosus muscle activation. Male professional field hockey players (n = 12) volunteered for the study. Paired t-tests were used to analyse the effect of ankle position on muscle NH_{BP}, eccentric peak torque and repetition time. Ankle dorsal flexion resulted in a higher NH_{BP} (p = 0.002, effect size [ES] = 1.48 [0.57 to 2.38]), repetition time (p = 0.004, ES = 0.98 [0.24 to 1.72]) and both absolute and relative heel contact force (p = 0.028, ES = 0.67 [0.01 to 1.34], p = 0.017, ES = 0.76 [0.07 to 1.44], respectively) compared to plantar flexion. Muscle activation was not significant different. This study showed a higher NH_{BP}, absolute and relative heel contact force and repetition time with a dorsal flexed ankle vs. a plantar flexed ankle in the NH_E, without changes in hamstrings muscle activation.

ARTICLE HISTORY
Received 11 August 2021
Accepted 30 December 2021

KEYWORDS
Strength training; Nordic hamstring break point; heel contact force; biomechanics; electromyographic

Introduction

Hamstring injuries have been postulated as a pandemic in sports and occur most commonly in sports involving frequent intense acceleration and deceleration actions, such as soccer or track and field (Junge & Dvořák, 2015; Valle et al., 2017). Modifiable risk factors for hamstring injuries encompass short biceps femoris fascicles (Bourne et al., 2015), low levels of strength (Ribeiro-Alvares et al., 2021; Timmins et al., 2016) and several other factors such as poor sprinting mechanics (Goode et al., 2015; Schuermans et al., 2017).

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Supplemental data for this article can be accessed here

The Nordic Hamstring exercise (NH_E) has been shown to reduce the incidence of hamstring injuries by 65%, when compliance is adequate (Goode et al., 2015). The effectiveness is of this exercise is thought to be related to its beneficial effects on risk factors of hamstring injuries such as knee flexor strength (Bautista et al., 2021; Vatovec et al., 2020), fascicle length (Cuthbert et al., 2020; Timmins et al., 2016) and sprint mechanics (Alt et al., 2021). The NH_E is an exercise where the athlete attempts to resist a forward-falling motion from a kneeling position, often while being supported at the ankle by a second individual. A benefit of the NH_E is therefore that it can be performed without the need of any extra material. However, numerous technical execution variables can influence the performance and hence effectiveness of this exercise. For example, time under tension and posture (e.g., pelvic tilt) during the NH_E execution may be important variables that influence training effects (Alt et al., 2018; Bautista et al., 2021; Van Hooren et al., submitted). Understanding of key technical variables and standardisation of these technical variables may therefore help to enhance training effects.

A key performance outcome to consider for the NH_E is the knee angle at the instant of downward acceleration. Typically, this is called the *Nordic Hamstring break point* (NH_{BP}; Sconce et al., 2021). After this point, hamstring muscle activation decreases, while biceps femoris long head fascicles rapidly lengthen (Van Hooren et al., submitted). Extending the NH_{BP} may be beneficial for strength adaptations, since a longer active range of motion in the NH_E might be associated with greater strength gains (Alt et al., 2018; Pallarés et al., 2021). Additionally, having the NH_{BP} at a larger knee angle may train the hamstrings at a longer muscle-tendon length, which better resembles the muscle-tendon unit lengths during which force has to be produced during sprinting (Van Hooren et al., submitted).

The ankle position has been previously suggested to be a key technical variable to influence the NH_{BP} (Comfort et al., 2017). Indeed, a neutral ankle position may put the gastrocnemius in a more favourable force-length relation compared to plantar flexion and hereby increase its contribution to the knee flexor moment (Ishikawa et al., 2007). This may in turn delay the NH_{BP}. Further, a neutral ankle position may better replicate the ankle position during terminal leg swing while running (Comfort et al., 2017; Yu et al., 2008). However, the effect of ankle position on the NH_{BP} remains unknown. Indeed, only one study so far has investigated the effect of the ankle angle during the NH_E and showed no differences either in biceps femoris long head or medial gastrocnemius muscle activation when maximal ankle plantar extension was compared to maximal ankle dorsal flexion during NH_E. However, they did not investigate the effects on the NH_{BP} or heel contact force (Comfort et al., 2017).

Therefore, the primary aim of this study was to investigate the effects of ankle position (i.e., plantar flexion or dorsal flexion) on NH_{BP}, repetition time and heel contact force during the NH_E. A secondary aim was to compare muscle activation in biceps femoris long head and semitendinosus muscles during both ankle positions. We hypothesised that maintaining ankle dorsal flexion during the NH_E would lead to a longer repetition time, later NH_{BP} and greater peak heel contact force compared to a plantar flexed position.

Method

Study design

Figure 1 shows the experimental set-up of the present study. A repeated-measures design was used to analyse the effect of ankle position (i.e., plantar flexion vs. dorsal flexion) on biceps femoris long head and semitendinosus muscle EMG activity, NH_{BP} and heel contact force during NH_E. On data collection day, the participants performed 2 sets of 3 repetitions of each ankle position condition of the NH_E (i.e., 4 sets in total) in a randomised and counterbalanced order while assessing muscle activation of the biceps femoris long head and semitendinosus muscle, knee angle and heel contact force. A 2-min recovery period was allowed between sets. To maintain control and yield comparable performances of each condition and set, each participant was familiarised with the protocols and instructed to perform each repetition with a maximal effort.

Participants

Male professional field hockey players (n = 12) volunteered for the study. Mean ±SD age, body mass and height were 22 ± 5.05 years, 79 ± 9.16 kg and 177 ± 3.84 cm, respectively. All subjects were professional filed hockey players from CPLV Valladolid, which plays in the European League, with a regular weekly exercise practice consisting of 4 hockey sessions (~9 hours), 3–4 resistance training sessions including strength/power exercises and 1 competitive match. The study was completed during the in-season competitive phase and all participants performed the same training program with the team during the duration of the study. All subjects had extensive experience with the NH_E, and did not modify their training habits to participate in this study. None of the participants reported using anabolic steroids or ergogenic aids. Subjects did not have a lower limb injury in the previous 6 months or severe hamstring muscles strain injuries in the previous 2 years. They were informed of the purposes and risks involved in the study before giving their informed written consent to participate. They were asked not to change their exercise

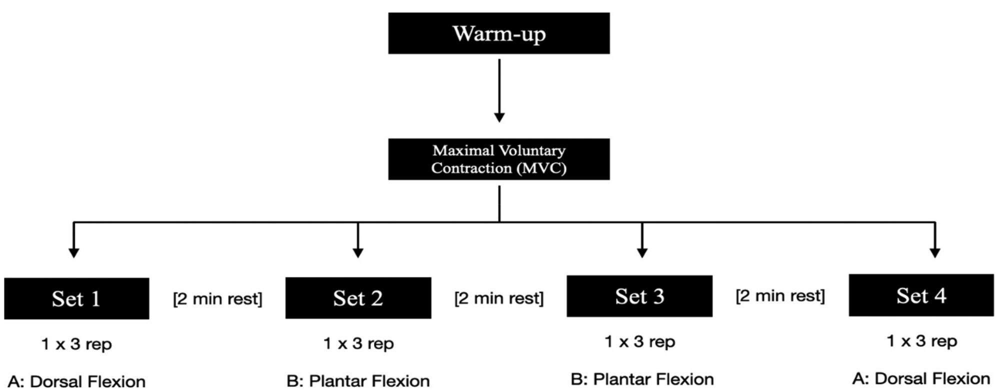

Figure 1. Schematic representation of the research design.

habits and not to perform resistance exercises for lower limb muscles two days prior to the measurements. The Ethics Committee of the University approved the study protocols. All participants completed all the conditions.

Sample size was estimated using the data from a previous study (Comfort et al., 2017) in which the effect of ankle position during the NH_E on biceps femoris long head muscle activation was investigated. Based on the Cohen d effect size of 0.64 for a possible difference in biceps femoris long head muscle activity changes between ankle position conditions, it was estimated that at least eight participants were necessary, with an alpha level of 0.05 and power ($1 - \beta$) of 0.80 (G*Power 3.1.9.2, Heinrich-Heine-Universitat Dusseldorf, Dusseldorf, Germany; http://www.gpower.hhu.de/). Considering possible dropouts and an measurement error, 12 participants were recruited.

Procedures

Two familiarisation sessions were performed before testing to ensure proper NH_E technique and to familiarise players with the custom-made NH_E device used in this study (Figure 2). The second familiarisation session was completed at least 48 h prior

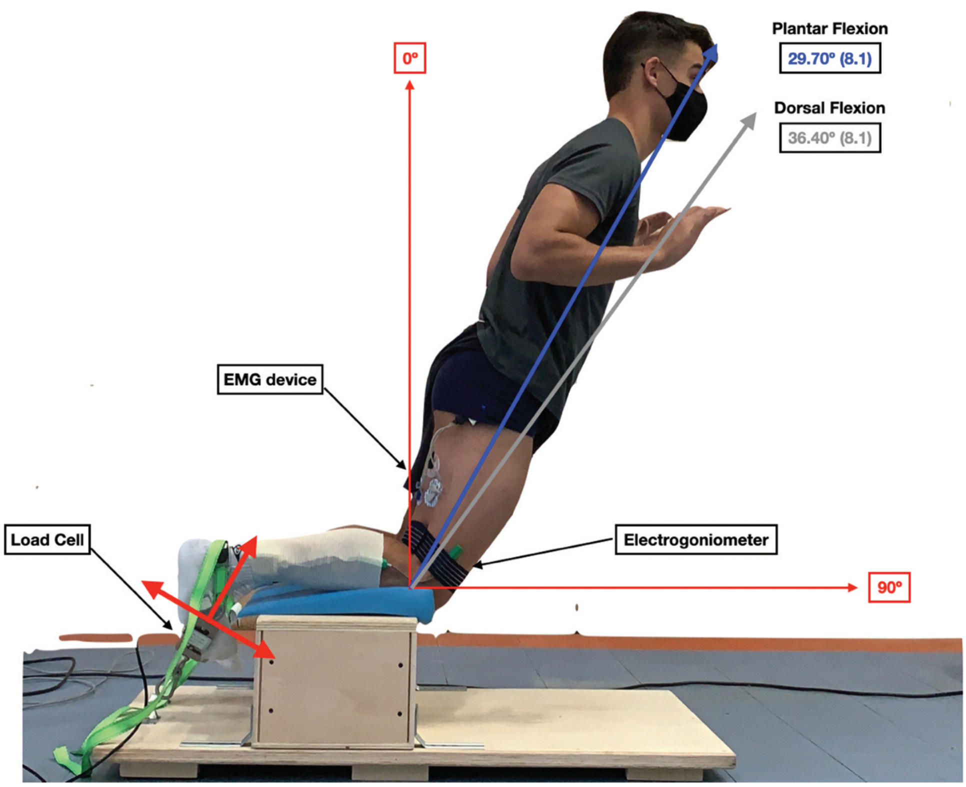

Figure 2. Representative participant during the Nordic hamstring exercise in the dorsal flexion condition. The blue line represents the Nordic Hamstring Break point in Plantar Flexion condition, the grey line the Nordic Hamstring Break Point in Dorsal Flexion condition. Red lines represent 0° and 90 knee angle.

to the testing day. These familiarisation sessions consisted on a video demonstration of NH_E technique, warm-up (consisted in 5 min of elliptical running at 8–10 km/h, and two sets of 10 seconds isometric 45° leg curl exercise) and 2 sets of 5 repetitions of the NH_E, one set of each ankle position condition, with a 3-min recovery period between sets. All familiarisation sessions were supervised by an experienced S&C coach.

Testing session consisted of 4 sets of 3 maximal eccentric-only Nordic curl repetitions while muscle activation of the biceps femoris long head and semitendinosus muscle, knee angle and heel contact force were assessed in the dominant leg, which was determined asking participants which leg they typically would use to kick a football on a target (Van Melick et al., 2017). Participants were placed in the custom-made NH_E device as shown in Figure 2. They were instructed to kneel on a pad with the patella free (i.e., the contact surface with the player was located at the level of the anterior tibial tuberosity), and they were attached to the platform at the ankle. Ankle fixation height was determined to be exactly the same as that of the tibia on the pad (i.e., tibia was parallel to the ground). From the 90° knee flexion position with hip in extension (0° hip flexion), players were instructed to perform each repetition with a maximal effort and in a controlled manner to reach an as low point as possible. The eccentric action was isolated, so the concentric action was performed using the upper limbs and the help of two assistants. Ankle position was randomly determined for each set and was maintained in the three repetitions. Plantar and dorsal flexion were set to the maximum ankle range of motion for each participant. To ensure the participants maintained the desired ankle position, a researcher stood behind the player to give kinaesthetic information about ankle location before and during each repetition. A 2-min break was applied between sets. Repetitions in which the participant was not able to maintain hip extension or ankle position were eliminated and were not considered in subsequent analysis. Before the first set, the same warm-up described above for the familiarisation was performed.

EMG assessment

Surface electromyogram (sEMG) amplitudes were measured from biceps femoris long head and semitendinosus muscles of the dominant leg using a MuscleLab system (V10.13, Ergotest Technology AS, Langesund, Norway). A bipolar configuration of two Ag/AgCl self-adhesive electrodes (1-cm inter-electrode distance; White Sensor WS, 79 mm, Ambu, Ballerup, Denmark) was placed in approximate alignment with the muscle fibres, as per the SENIAM guidelines (Hermens et al., 1999) and was checked using ultrasound. The skin beneath the electrodes was shaved, abraded and cleaned with alcohol to reduce inter-electrode resistance prior to testing session. EMG data were collected synchronously with force data during each contraction and were amplified (×1000) and filtered using a 20–500 Hz band-pass filter and converted online to root-mean-square EMG (EMG_{RMS}) with a 100-ms symmetrical moving average window. For analysis, maximal EMG_{RMS} for both biceps femoris long head and semitendinosus muscles was collected during a maximum isometric 45° leg curl exercise contraction prior to testing (Figure 1) and used to normalise the EMG data. From a total of 10 sec of maximum isometric 45° leg curl performed by each participant, a total of 5 sec were analysed to obtain the maximal $EMG_{RMS.}$ The EMG_{RMS}/EMG_{MAX} ratio was considered an estimate of central drive to the muscle and used to determine muscle activation during the NH_E.

$NH_{Break\ Point}$ assessment

The knee angle of the dominant leg was measured using an electrogoniometer (V10.13, Ergotest Technology AS, Langesund, Norway) to determine the NH_{BP} and knee angular velocity of each repetition. The electrogoniometer sensors were fixed to the skin on the lateral side of the dominant leg, in the line between the greater trochanter and the femoral condyle and between the femoral condyle and the ankle malleolus at a distance of approximately 3 cm from the knee transverse axis. The electrogoniometer was synchronised with the EMG signal and with the force sensor through the MuscleLab system. Angle and angular velocity were amplified (×1000) and filtered using a 20–500 Hz band-pass filter with a 100-ms symmetrical moving average window. 90°-knee flexion was established as the starting point, with a researcher determining the position with a manual goniometer before each set. The beginning and the end of NH_E repetition was determined from 90° of knee flexion until the NH_{BP}. The NH_{BP} was defined as highest angular acceleration of the knee (Alt et al., 2018) at which the individual can no longer resist the increasing gravitational moment and falls to the floor (Sconce et al., 2021). Repetition time was determined as the time between start and the NH_{BP} (see supplementary File I).

NH_E eccentric heel contact force assessment

Heel contact force of the dominant leg was assessed using a strain gauge (V10.13, Ergotest Technology AS, Langesund, Norway) with sample frequency of 200 Hz. This force sensor was placed between the heel strap and the platform (Figure 2). The mean heel contact force of the two repetitions performed for each condition was used for analysis. In addition, relative heel contact force was calculated as the absolute value of contact force divided by body mass.

Statistical Analysis

All variables were expressed as mean and standard deviation (SD). All variables met the normality assumption (i.e., Shapiro-Wilk test, $p > 0.05$). Absolute and relative reliability was calculated using standard error of measurement (SEM) and Intraclass Correlation Coefficient ($ICC_{2.k}$; Weir, 2005). Paired t-tests were performed to analyse the effect of ankle position on NH_{BP}, heel contact force and repetition time. In addition, to analyse the effect of ankle position (i.e., plantar vs. dorsal flexion) on muscle EMG activity (i.e., semitendinosus vs. biceps femoris long head) a 2-way repeated measures analysis of variance (RM ANOVA, 2 × 2) was performed. The Bonferroni post-hoc procedure was used to adjust for multiple comparisons. The effect size (ES) was calculated though Hedges' formula, where the pooled SD was used as denominator: $c(df) = 1 - \frac{3}{4x(df-1)}$.

The level of significant was set at $p < 0.05$. All statistical test were performed using the software package R_{studio} (1.3.959, 2009–2020, PCB). Figures were created using adapted code from Van Langen (2020).

Results

Table 1 summarises the descriptive statistics of muscle activation for the semitendinosus and biceps femoris long head, NH_{BP} and heel contact force for each ankle position.

Absolute and partial reliability analyses of both conditions are presented in supplementary file I.

Paired t-test revealed that there were statistical significant differences in NH_{BP} ($t_{[11]}$ = −4.19, p = 0.002. ES = −1.48 [−2.38 to −0.57]), duration ($t_{[11]}$ = −3.61, p = 0.004, ES = −0.98 [−1.72 to −0.24]), heel contact force ($t_{[11]}$ = −2.54, p = 0.028, ES = −0.67 [−1.34 to −0.01]) and relative strength ($t_{[11]}$ = −2.79, p = 0.017, ES = −0.76 [−1.44 to −0.07]) in favour to the dorsal flexion condition, see, Figure 3 for more details.

Regarding muscle electromyographic activation, the 2-way RM ANOVA (2 x 2) did not show a significant main effect of 'muscle' ($F_{[1, 11]}$ = 3.04, p = 0.109), '*ankle position*' ($F_{[1, 11]}$ = 0.44, p = 0.521) or interaction effect of '*muscle x ankle position*' ($F_{[1, 11]}$ = 0.11, p = 0.748).

Discussion and implications

The purpose of this study was to assess the effect of ankle position on heel contact force, NH_{BP} and repetition time during NH_E. In addition, biceps femoris and semitendinosus muscle activation were investigated. Our findings show no influence of ankle position (i.e., plantar vs. dorsal flexion) on muscle activation of the biceps femoris long head or semitendinosus. However, the dorsal flexion condition resulted in a longer repetition time as well as higher heel contact force and greater NH_{BP} in comparison to the plantar flexion condition.

The main finding of this study was that the use of a dorsal flexed ankle during NH_E allowed participants to obtain a greater repetition time, more absolute and relative heel contact force and a later NH_{BP} in comparison to the plantar flexed condition (see, Figure 3). The finding that using a simple modification of NH_E technique from plantar to dorsal flexion increased absolute and relative contact force by 13% could have

Table 1. Descriptive statistics (mean, standard deviation and SD of mean difference) of each dependent variables in ankle plantar and dorsal flexion.

Variable	Plantar flexion	Dorsal flexion	Mean ± SD difference	Percentage of change
NH_{BP} (degrees)	29.7 ± 8.1	36.4 ± 8.1	6.7 ± 4.23	18
Repetition duration (sec)	3.39 ± 0.86	4.17 ± 1.14	0.78 ± 0.74	19
Heel contact force (N)	357 ± 87	410 ± 98	53 ± 73.07	13
Relative heel contact force (N/kg)	4.51 ± 0.89	5.17 ± 0.89	0.66 ± 0.81	13
ST_{EMG} (% MVC)	77.0 ± 19.73	75.5 ± 18.60	−1.50 ± 8.21	−2
BF_{EMG} (% MVC)	66.2 ± 13.94	64.0 ± 16.77	−2.2 ± 11.98	−3

ST_{EMG} = semitendinosus electromyography, BF_{EMG} = biceps femoris long head electromyography, NH_{BP} = nordic hamstring break point, %MVC = percentage of maximal voluntary contraction.

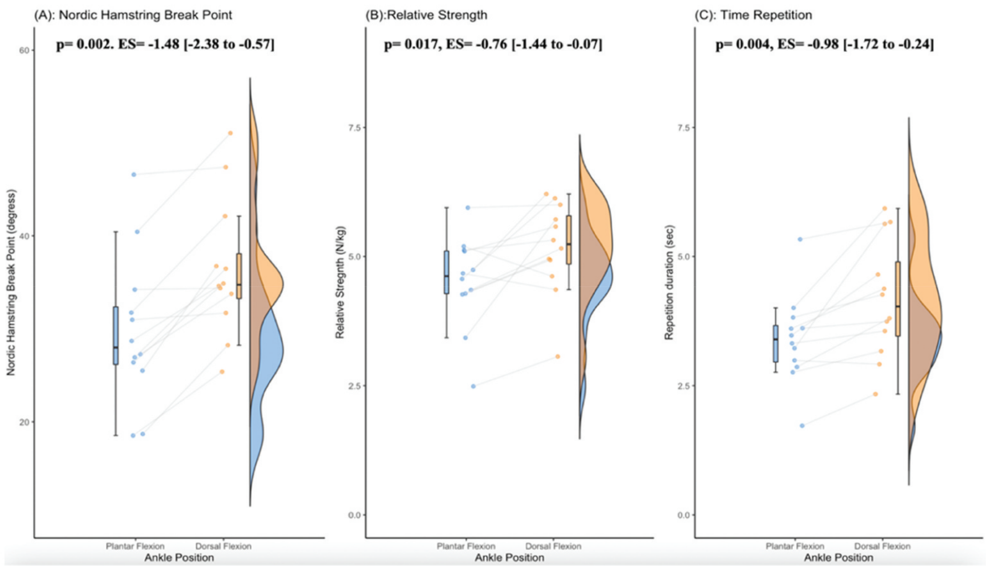

Figure 3. Graphical represent of Nordic Hamstring Break Point (a), ankle reaction force (b) and Repetition Time (c) during Nordic Hamstring Exercise in regard to ankle position. Centre lines represents the medians: box limits indicate the 25^{th} and 75^{th} percentiles. Whiskers extended 1.5 times the interquartile range from the 25^{th} and 75^{th} percentiles. The right side of each plot shows the distribution of each variable.

important consequences for intervention studies as it suggests standardisation of the ankle angle is required to perform a valid assessment of NH_E strength and the NH_{BP}. Indeed, a recent meta-analysis by Bautista et al. (2021) revealed that none of the 17 included studies that used the NH_E as a primary intervention reported descriptive details about ankle position during the NH_E. As such, the intervention effects on eccentric knee flexors strength could at least by partially explained by changes in ankle positions from pre to post intervention.

Despite the NH_E has been extensively investigated over the past 15 years, only one study have performed a comprehensive kinematic and kinetic analysis of the NH_E (Van Hooren et al., submitted). However, no intervention studies have provided profound insights on how time under tension could benefit eccentric hamstring force production. This might be due to a limited number of technical opportunities (e.g., NH_E executed on a dynamometer). Another limitation is that NH_E execution has usually been based on slow target velocities indicated as average cadence (e.g., 30°/s), where participants were requested to perform the braking movement as slow as possible. Consequently, the time under tension near full knee extension was frequently very short due to neuromuscular fatigue (Delahunt et al., 2016; Ditroilo et al., 2013; Lovell et al., 2018). This might have diminished the training progress as this specific ROM (30–0° knee flexion), where muscle operates at long fascicle length which is presumably crucial for an effective strength program in sports (i.e., injury prevention and competitive success) (Guex et al., 2016; Timmins et al., 2015). For such reason, we hypothesised that participants' placement (e.g., ankle position) during the NH_E might enable us to perform the exercise not only during more time (i.e., longer time under tension) but also closer to knee total extension may benefit training-induced effects on fascicle length where muscles are capable to apply more force.

Our results showed no significant differences in semitendinosus and biceps femoris long head muscle activation with changes in ankle position. This finding was in accordance with previous research that showed no significant differences in biceps femoris muscle activation with changes in ankle position (Comfort et al., 2017). However, in that study, muscle activation of the biceps femoris correspond to 124% of MVC, which is much higher than our participants (66% and 64% for plantar and dorsal flexion, respectively). These differences could be explained by the sport background of the individuals. Participants in Comfort study were soccer or rugby players whereas our study included field hockey players. Furthermore, in Burrows et al. (2020) study, young soccer players showed similar sEMG values of semitendinosus and bicep femoris activations after NH_E (i.e., 70% and 75% of MVC, respectively). These findings therefore suggest that the change in ankle position did not change the contribution of the hamstrings to knee flexor torque production. Instead, changing of the ankle position may have put the gastrocnemius in a more favourable part of the force-length relation, hereby increasing its force-producing capability and hence contribution to the knee flexor torque.

With regard to implications for training, the effectiveness of the NH_E on improvements in knee flexor strength, sprint performance and injuries are likely associated with variables such as exercise volume and intensity of the exercise (Bourne et al., 2017; Opar et al., 2015; Timmins et al., 2016). Training volume manipulation is relatively easy to accomplish by changing the number of repetitions or sets and may also be impacted by manipulating time under tension. However the intensity is more difficult to manipulate because the exercise is typically performed with body weight only. The time under tension and peak torque/force that muscles have to produce are likely important variables that explain training effects (Alt et al., 2018). For example, a longer time under tension has been associated with improvements in musculotendinous morphological changes and power movements. Similarly, higher peak loads have been associated with larger increases in muscle strength due, primary, by an accumulation of mechanical tension and metabolic stress (Oranchuk et al., 2019). By changing the ankle position, the time under tension and peak heel contact force increased and on the long term, such increases may therefore transfer into more strength adaptations. However, since the change in ankle position may not change the force production of the hamstrings (but rather of the gastrocnemius), it will likely not directly improve the stimulus for strength adaptations to the hamstrings. Nevertheless, since the peak force may occur at longer muscle-tendon unit lengths that better replicates the muscle-tendon unit and likely fascicle lengths during which force has to be produced during the terminal swing phase of sprinting (Van Hooren et al., submitted), it can still be beneficial to use a dorsal flexed ankle position during the NH_E. Additionally, the longer time under tension may also enhance training adaptations.

One of the main limitation of this study was that we did not measure ankle angle and we did also not assess actual muscle forces, but instead contact force at the heel, which has not a strong relation with hamstring forces (Ruan et al., 2021). As a result, further research is required to confirm the hypothesis that using dorsal flexion leads to better improvements in eccentric strength of knee flexors and other outcomes. Interventions studies are needed to confirm the hypothesis that using a dorsal flexion leads to better improvements in eccentric strength of knee flexors and other outcomes relevant to sports performance or injuries. At this point, it is important to point out that the moment arm and angle of force are likely to vary between participants. For this reason, heel force cannot be used to calculate knee torque. However, since the participants' moment arm and angle of force remained constant between trials, the increased force magnitude likely resulted in a larger knee flexion moment.

Another limitation was that we used a 45° of the knee joint to normalise the hamstring muscle sEMG activity. However, previous research has been showed that normalising is dependent on the knee joint angle (Onishi et al., 2002). Furthermore, the gastrocnemius muscle electrical activity was not evaluated, although previous research has shown no effects of ankle position on gastrocnemius electrical activity (Comfort et al., 2017). Finally, there are different methods to determine the breakpoint (Sconce et al., 2021). However, we used the same method for both ankle positions and this is therefore unlikely to have an impact on our findings.

Conclusions

This study showed a later NH_{BP}, higher absolute and relative eccentric peak heel contact force and longer repetition time during a NH_E with a dorsal flexed ankle compared to a plantar flexed ankle. These changes occurred without significant differences in hamstrings muscle activation, suggesting they reflect a larger contribution of the gastrocnemius.

Acknowledgments

The authors would like to thank to all participants that took part in this study.

Data availability statement

Authors are happy to share the database upon request.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The author(s) reported there is no funding associated with the work featured in this article.

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