Kinetic and electromyographic responses to traditional and assisted Nordic hamstring exercise.

ABSTRACT

The Nordic hamstring exercise (NHE) is performed to increase hamstring strength, elicit morphological changes and reduce injury risk. However, to date the NHE assisted by the means of an external resistance, has not been investigated. Thus, this study compared the eccentric knee flexor strength, rating of perceived exertion (RPE) and electromyographic responses of the biceps femoris (BF) and semitendinosus (ST) when performing the NHE under assisted or unassisted conditions. Sixteen professional soccer players (19.4 ± 2.2 years old) performed 5 sets of 3 NHE unassisted and with assisting loads (5% to 20% of body mass) using the Keiser^{TM} machine. Eccentric knee flexor strength was measured from the participants dominant limb. Peak surface electromyography (sEMG) of the BF and ST was recorded from the dominant limb, the ratio was also calculated. Participants rated the intensity of each condition of the NHE on a ten-point RPE Borg scale. All assisted conditions displayed significantly lower ($p < 0.05$) absolute and relative eccentric knee flexor strength compared to unassisted conditions. RPE for each loading condition was significantly lower ($p < 0.05$) as assisting load increased except for the difference between the 10% and 15% assisted conditions. sEMG of the BF and ST was not significantly lower ($p < 0.05$) during all assisted conditions compared to the unassisted NHE, neither were there significant between muscle differences or sEMG ratios. Our findings suggest that the assisted NHE reduces the load and difficulty of the exercise. Practitioners can use the assisted NHE to manipulate intensity and difficulty if that is appropriate for their programming.

Key words: Eccentric Strength, Neuromuscular, Soccer

INTRODUCTION

The Nordic hamstring exercise (NHE) is a popular training and injury reduction exercise (3,34,43). The NHE as referred to in this study is an eccentric movement performed while kneeling and with the ankles in a fixed position. The upper body moves towards the ground generating knee joint extension and resisted lengthening of the hamstrings, while an open hip angle is maintained (3). The eccentric knee flexor strength required to perform the NHE exceeds concentric capabilities eliciting substantial neuromuscular and morphological adaptations such as increased fascicle length leading to improved length-tension in the hamstrings (49). As a result, hamstring injury incidence is reduced, particularly in team sports where strain injury to the biceps femoris (BF) is common among soccer players (1,2,16,17,40,43,48). van der Horst et al. (47), observed that when soccer players completed a 13-week pre-season NHE programme, hamstring injury occurrence rate was significantly reduced by prescribing 2-3 sets of 5-10 reps progressively over the intervention period. This evidence supports the prescription of the NHE for athletes at risk of hamstring injury (2,17,44).

To date only the traditional NHE (i.e. unassisted) has been investigated. When studying the NHE Bourne et al. (7) found that the BF muscles and the medial hamstrings activate between 72-91% and over 82-102% respectively when using surface electromyography (sEMG) by normalising the sEMG signal relative to isometric or eccentric contractions (8,15). Delahunt et al. (15) also observed high BF and medial hamstrings sEMG values during the NHE, reporting 80% and 90% of the maximal voluntary eccentric contraction (MVEC), respectively. Clearly, the NHE is performed at near to maximal intensity, and in certain conditions the NHE also produces supramaximal BF activation (134% of MVEC) when compared with maximal eccentric knee flexor contractions on an isokinetic dynamometer (15). Lower sEMG values were observed when signals are normalised to muscle activation during explosive hamstring actions such as treadmill sprint running (46). For example, van den Tillaar et al. (46) found that the NHE sub-maximally activated the medial hamstrings (60-70%), and even less the BF (30-40%) when sEMG signals were normalised to sprint running. Clearly, the traditional NHE activates the hamstrings at near to maximal intensity when compared to isometric or eccentric exercises that have a kinematic resemblance to the NHE. Therefore, assisting the exercise may reduce neuromuscular activation of hamstring muscles, practically meaning an easier workload in turn allowing the strength and conditioning coach to adjust exercise intensity when appropriate. Furthermore, when using sEMG normalised to maximal isometric contractions, Bourne et al. (8) found that the semitendinosus (ST) and semimembranosus (SM) activate more than biceps femoris (BF) during the traditional NHE. Mendez-Villaneuva et al. (29) also found that the NHE activates ST and BF short head (BFSH) more so than the SM and BF long head although this was analysed using functional magnetic resonance imaging. Furthermore, superior activation of the ST during hamstring focused exercises is not uncommon as Bourne et al. (8) also found that the ST was also the dominant muscle in nine other common hamstring exercises during the eccentric phase of movement. Assisting the NHE may alter the balance of muscle activation in the hamstrings making this method of assistance useful to the strength and conditioning coach on the basis that this could lead to positive adaptations in muscle strength, reducing the risk of muscle failure and injury (20,44).

High muscle activation is caused by the excessive eccentric action of the NHE. Eccentric knee flexor strength displayed during the NHE can exceed 300N of absolute unilateral force, or 3.8-4.1 N·kg of relative strength, from the dominant limb of soccer players and in other team sports (6,34,43). Timmins et al. (43) reported that 309.5N of absolute strength was displayed by uninjured players and 260.6N by previously injured limb's and 262.6N for their contralateral limb. High eccentric forces observed during the NHE are thought to elicit positive architectural changes in the hamstring muscles that are thought to be associated with injury risk reduction (5,43,44). Receiver-operator-characteristic-curve analysis provided a minimum threshold of 337N to indicate a reduced relative risk of injury among soccer players (43). Other studies have reported similar figures of 256-279N of absolute unilateral force in Australian footballers and 267.9N in rugby union players (6,34). Timmins et al. (43) also used logistic regression to find that increasing eccentric knee flexor strength by 10N can reduce the risk of hamstring strain injury by 8.9%. These figures represent the average measurements of knee flexor force from each study. It is not yet known what effect assisting the NHE will have on eccentric knee flexor force and how this might affect the assessment of hamstring injury risk which may be enlightening for the strength and conditioning coach to consider when prescribing the best possible exercise.

The findings above are based on the use of the traditional NHE during training (i.e. unassisted). However, in an article of opinion, Matthews (26) demonstrated practical evidence to show that elastic bands and partner resistance can assist the NHE, also supported by a more recent study (10). Such intervention would change the eccentric intensity of the exercise as showed in the findings of Buchheit et al. (10) resulting in a lower perception of effort as the relationship between perceived effort and reduced exercise load has been established and also suggesting a possible neuromuscular activation alteration (27,29). Therefore, reducing the load of the NHE by assisting the movement may be a way of reducing the exercise intensity as perceived by the athlete, which could benefit the strength and conditioning coach when they wish to alter the difficulty of the exercise (12). The magnitude of load reduction should be reduced as a portion of bodyweight (i.e. %10 of 90kg participant = 9kg load reduction) meaning that loads are relative to the participant. Yet, currently no evidence is available to understand the effect of assisted conditions ranging from 5-20% bodyweight will have on eccentric knee flexor strength, sEMG activity or perceived exertion during the NHE. Therefore, the goal of this study was to evaluate acute kinetic and electromyographic responses of the assisted NHE compared to the traditional NHE. These evaluations could change the perspective on the way that the NHE is administered and find openings for future research. We hypothesised that unloading the NHE would reduce the perception of the effort and knee flexor strength, while eliciting substantial neuromuscular activation.

METHODS

Experimental approach to the problem

This study used a randomised repeated measures design to assess eccentric knee flexor strength, sEMG activity of the hamstrings, and rating of perceived exertion (RPE) during the NHE. All measurements were collected from the participant's dominant limb while performing the NHE bilaterally either unassisted or with assisting loads of 5, 10, 15 and 20% of body mass provided by a cable resistance machine. All measurements were taken from the dominant limb and this was identified as the participants preferred ball-striking leg. The assisting loads were limited to 20% and below in line with previous research that has investigated using relative body mass with exercise, more importantly little direct evidence is available to suggest appropriate assisting loads. Participants were under the instruction of the investigators while performing all repetitions and each participant had experience of performing the assisted and unassisted NHE.

Subjects

Sixteen young professional male soccer players (age 19.4 ± 2.2 years; height 180.4 ± 8.8 cm; body mass 75.8 ± 11.5 kg; dominant limb 4 left, 12 right) volunteered to participate in this study providing written informed consent. A priori sample size calculation was conducted using relative bilateral eccentric knee flexor force pilot data from four participants. The sample size calculation was made using G*Power software (version 3.1, Universitat Dusseldorf, Germany). Expected effect size was 0.32 based on the magnitude of effect sizes suggested by Rhea (38) and power was set at 80% with an alpha level of 0.05 resulting in a sample size of 15. All participants had at between three and seven years of strength training experience. At the time of data collection, participants were regularly completing 2-3 prescribed strength training sessions per week that included eccentric loading of the hamstrings. All participants were professional players for the soccer club where this research was conducted. At the time of the study all participants were healthy and had been free from hamstring injuries for at least 12-months previously. Ethical approval for this research was granted by the St Mary's University ethics committee according to the declaration of Helsinki.

Procedures

Data collection for this study took place over a four-day period in-season during which the participants were on a break from competition. This break coincided with reduced on-field and strength training volume. In the five days prior to testing, participants did not perform eccentric exercises that loaded the hamstrings in order to avoid muscle damage and fatigue pre-trial. Because of logistics and training schedule constraints, participants completed the experimental protocol during different stages of the training day (i.e. before or after on-field training).

***** Insert Table 1 here *****

Prior to data collection the participants completed the warm-up protocol described in Table 1. At the end of the warm-up participants performed a maximal voluntary isometric contraction (MVIC) using their dominant limb, so that sEMG recordings during the NHE could be normalised. The MVIC was performed in a prone position with knee flexion at 160° and the hips at 0° flexion against an isometric dynamometry system (Figure 1). Participants performed two MVICs which lasted for 5-seconds and were separated by 1-minute rest. The mean peak root mean square (RMS) sEMG of both trials were retained for further analysis. Three minutes after the recording of the MVIC, participants performed five sets of three NHE repetitions at the varying levels of load whilst recording RMS sEMG, knee flexor strength and RPE. Each set was separated by a three-minute rest period during which the participant remained inactive, to allow for sufficient recovery (14). Assisting load was provided using the Keiser^{TM} machine (Infinity Series: Functional Trainer, Keiser^{TM}, CA, USA), which used pneumatic pressure to provide resistance measured in kilograms. A custom-made attachment was used to connect the participant performing the movement to the Keiser^{TM} device (Figure 2b). The order in which assisting loads conditions were performed was randomised using the simple randomisation function in Microsoft Excel 2016 software (Microsoft Corporation, Redmond, WA, USA).

***** Insert Figure 1 here *****

The Nordic Hamstring Exercise

Participants began the NHE by kneeling on an Airex balance pad (Airex AG, Sins, Switzerland) for comfort with the torso upright, the hips at 0° of flexion and the knees flexed at 90°. The movement was initiated by the participant extending their knees while maintaining the position of the hip and torso until reaching full range (180°) of knee extension. The movement lasted approximately 5-seconds and finished when the participant had reached the ground. To attempt to achieve consistent angular velocity, the NHE was performed following instructions of the researcher counting "5s, 4s, 3s, 2s, 1s" during the descent. Each repetition was separated by a ten second rest period. No concentric portion of the movement was performed.

Rating of perceived exertion

Following the completion of each set participants were immediately asked by the researcher to verbally give a rating of perceived exertion referring to the intensity of the exercise on a ten-point Borg scale (4). Measuring perception of effort with this scale is considered a valid tool to subjectively measure what internal demands the individual is experiencing (23,35). Importantly, subjective responses should specifically refer to the area and sensation under investigation which in this instance was the intensity of the exercise on the hamstrings (35).

***** Insert Figure 2a-c here *****

Eccentric knee flexor dynamometry

Eccentric knee flexor strength of the dominant limb was measured during the performance of the NHE by a wireless digital static force gauge dynamometer using a sample rate of 10Hz (JTECH Commander Echo, JTECH Medical. Midvale, Utah, USA). Hand-held and fixed dynamometry has been previously used to assess isometric and eccentric hamstring strength in young soccer players (30,36,42). The dynamometers were attached to a metal-framed rig (Figure 2a) with a custom-made attachment (Figure 2c) that allowed for the application of force at a perpendicular angle (Kanga-Tech, North Melbourne, Victoria, Australia). The customised system used in this study has been used in the methods of published research to assess hamstring strength (24). The research associated with the dynamometry system is novel. Peak eccentric force measured by the dynamometer was transmitted digitally on to KangaTech software (Kanga-Tech, North Melbourne, Victoria, Australia). Force measured during the NHE was calculated and reported in absolute terms and relative to participant mass. The mean scores from three trials of each condition were calculated for statistical analysis.

Electromyography

sEMG signals of the BF and ST muscles of the dominant limb were continually recorded during the performance of the MVICs and the NHE. Signal was sampled at 1000Hz and band pass filtered (20-450Hz) using a portable data acquisition system (Biometrics DataLOG MWX8; Biometrics LTD. Newport, UK) with sEMG sensors (SX230 EMG Sensor, Biometrics LTD. Newport, UK). RMS value was calculated over a window of 250ms. Peak RMS sEMG of two repetitions of the MVICs were calculated as a mean. Peak RMS sEMG from three trials of each condition of the NHE were calculated relative to MVIC. Relative peak RMS sEMG data were also used to calculate the ratio of BF to ST activity. Measurement of sEMG activity was conducted by shaving and cleansing the skin to lower skin impedance (19). Electromyography sensors were taped to the skin to avoid motion artefact (19). Two electrodes were placed on the posterior thigh midway between the ischial tuberosity and the tibial epicondyle parallel to each other. Palpation of the muscle belly and active external-internal rotation of the knee in 90° flexion helped to identify the optimal area of electrode placement. A pre-gelled hypoallergenic one-centimetre snap electrode (Performance Plus, Vermed, VT, USA) was placed on the greater trochanter of the right hip to measure a reference signal. The use of sEMG, as described here, was done so under the guidelines of the Surface Electromyography for the Non-Invasive Measurement of Muscles (SENIAM) group (http://www.seniam.org).

Statistical analyses

All participant sEMG and eccentric knee flexor force recordings for all repetitions of the NHE were calculated as a mean for the level of loading condition. These data, along with the RPE values provided by participants was then used for further statistical analysis. Statistical analysis was performed using SPSS (IBM SPSS statistics; version 22, Chicago, IL, USA). Data are presented as arithmetical mean and standard deviations. Two-way mixed-effects, absolute intraclass correlation coefficients (ICC) including 95% confidence intervals (CI) and standard error of the mean (SE) were calculated using recordings of peak absolute eccentric knee flexor force and the sEMG of the BF and ST during the unassisted condition. Repeated measures analysis of variance (ANOVA) with 5 conditions (loading conditions) was used to analyse the differences of rating of perceived exertion, peak RMS sEMG of individual muscles, BF to ST ratio and eccentric knee flexor force (absolute and relative). Prior to performing the ANOVA, data was analysed to check for skewness and kurtosis. A two-way repeated measures MANOVA with five conditions (loading conditions) was used to analyse the differences of BF and ST activation across the different loading conditions. Prior to performing the MANOVA, the data was analysed for skewedness and kurtosis as well as homogeneity using Levene's and Box's tests. Where the Wilks-Lambda F value from all ANOVA provided a statistically significant difference between the measures, Bonferoni post-hoc analysis was used to identify the difference between means within the data set. The level of statistical significance to detect a difference in means was set at $p < 0.05$. Partial eta squared (η_p^2) was used to interpret effect sizes for all ANOVA and MANOVA. The square root of the η_p^2 was converted to a Cohen's d value as described by Rosenthal (39). Changes were considered trivial <0.2; small 0.2-0.6; medium 0.6-1.2; and large >1.2 based on Rhea's (38) interpretation of Cohen (11).

RESULTS

The ICC and *SE* for the recordings of peak absolute eccentric knee flexor force of the participants dominant limb was 0.89 (CI: 19.42) and ± 78 N respectively. The ICCs and *SE* for the sEMG recording of the BF were 0.84 (CI: 7.46) and ± 20 % MVIC respectively. The ICCs and *SE* for sEMG recordings of the ST from the participants dominant limb were 0.95 (CI: 4.70) and ± 26 % MVIC respectively. Acceptable reliability was achieved for all sEMG and eccentric knee flexor force measures, based on the ICCs calculated.

Assisting the NHE significantly reduced absolute ($F(4, 12) = 7.21$, $p = <0.01$, $\eta_p^2 = 0.71$) and relative ($F(4, 12) = 14.93$, $p = <0.01$, $\eta_p^2 = 0.83$) eccentric knee flexor force with large effect sizes. It should be considered that the mean relative eccentric force data for the unassisted condition were non-normally distributed with skewness of 1.71 (*SE* 0.6 N•kg). Reductions in eccentric knee flexor force occurred in-line with increases in assisting load. Significant reductions in eccentric knee flexor force were observed between the unassisted condition and all assisted conditions ($p < 0.05$). Other non-significant differences were observed between the 5 and 10% assisted conditions for relative ($p = 0.37$) and absolute ($p = 0.62$) eccentric knee flexor strength. As well as the 15 and 20% assisted conditions for absolute ($p = 1.0$) and relative ($p = 0.57$) knee flexor strength. Mean absolute and relative eccentric knee flexor strength of the participants, including significant comparisons between the unassisted and assisted conditions are demonstrated in Figures 3 and 4.

***** Insert Figure 3 here ****

***** Insert Figure 4 here ****

Non-significant linear reductions in muscle activation were observed between the unassisted condition and other assisted conditions in both the ST (F (4, 12) = 1.67, $p = 0.22$, $\eta_p^2 = .36$) and BF (F (4, 12) = 3.17, $p = 0.54$, $\eta_p^2 = .52$). The range of mean relative muscle activation across the conditions (unassisted to 20% assisted) was 11.6% and 14.8% for the BF and ST respectively (Figure 5). Furthermore, low to moderate observed statistical power was generated from analysis of the BF (0.64) and ST (0.37). However, a large effect size was calculated from the differences in BF ($\eta_p^2 = .52$) and ST ($\eta_p^2 = .36$) activation.

***** Insert Figure 5 here *****

When comparing between-muscle differences, the two-way repeated measures MANOVA revealed no significant main effect in sEMG between individual muscles across the different conditions of assisting load (F (8, 148) = 1.43, $p = 0.19$, $\eta_p^2 = 0.72$). Importantly, moderate observed statistical power (0.63) and large effect size ($\eta_p^2 = 0.72$) were generated from this multivariate analysis. Furthermore, in the analysis of between muscle differences, BF to ST ratios showed that the BF was more active across all loading conditions, with a small effect size although this was not significant (F (4, 12) = 0.32, $p = 0.86$, $\eta_p^2 = 0.01$) (Table 2).

***** Insert Table 2 here *****

RPE scores were significantly reduced between the loading conditions with a large effect size(F (4, 12) = 13.44, $p = <0.01$, $\eta_p^2 = .82$). Linear reductions in RPE occurred alongside an increase in assistive load. Comparisons between conditions, including significant differences between the unassisted condition and all assisted conditions are demonstrated in Figure 6. There were significant differences between all loading conditions except for the difference between the 10% and 15% assisted conditions (p = 1.0) where mean RPE was 5.06 ± 1.30 and 4.75 ±1.80, respectively. The mean RPE scores for the unassisted condition was non-normally distributed, with skewness of -1.24 (*SE* 0.61) and kurtosis of 1.07 (*SE* 1.22).

***** Insert Figure 6 here *****

DISCUSSION

This was the first study to quantify knee flexor force, hamstring muscle activation and RPE of the NHE using different assistive loads. The main findings were that significant reductions in eccentric knee flexor force and RPE were observed when performing assisted NHE compared to traditional NHE. However, hamstring neuromuscular contribution did not significantly change between individual muscles across the loading conditions, neither were there changes in individual muscle activation ratios.

In our study, the use of Keiser^{TM} resistance technology was integral to the way in which eccentric knee flexor strength was assessed. The pneumatic resistance that the Keiser^{TM} uses does not change the momentum of load at any speed meaning that the resistance is the same throughout the NHE. Table 3 demonstrates how pneumatic assistance affects knee flexor strength relative to the unassisted NHE. Non-investigative reports about the assisted NHE have either used resistance bands or partner-controlled resistance (26). This is not ideal when trying to measure outputs of the NHE (figure 7) as variances in deformation and resistance when using bands or the inevitable variability of assistive load with a partner will affect the way in which the exercise is performed. As a result, the control of assistive load is an important factor when comparing the findings of this study to future research investigating the NHE.

***** Insert Table 3 here *****

***** Insert Figure 7 here *****

Measures of eccentric knee flexor force during the NHE in this study are considerably high with relative and absolute forces ranging from 4.4-5.8 N·kg and 315.8-430.4 N respectively. It is difficult to make direct comparisons to previous research because the differences in the equipment used to measure knee flexor forces. However, the reliability statistics reported in this study are very similar to those reported by the other devices used and further to this comparisons between difference devices could be a feature of future research (34). With this in mind, direct comparisons are not possible but it is worth considering other reported results. Soccer players have previously been reported to display eccentric knee flexor strength of 309.5 ± (73.4) N and 4.1 (±0.9) N·kg as an absolute and relative unilateral average respectively (43). Similarly, Australian rules footballers respectively recorded absolute and relative unilateral eccentric knee flexor strength as 323.0 (±80.0) N and 4.1 (±1.0) N·kg (34). Sub-elite rugby union players displayed absolute and relative scores of 367.7 (±85.0) N and 3.9 (±0.9) N·kg. Our results show that with greater assistive loads (10-20% body mass), high eccentric knee flexor forces can be produced and smaller assistive loads elicit even greater knee flexor forces. In consideration of this, assistive loads may allow for more control of the free fall of the body implying greater range of motion of the knee joint. This in turn may facilitate superior force development due to an increase in mechanical load and perhaps the achievement of the optimal muscle length (9). Hence, assistive loads promote the ability to produce high force, which in turn suggests potential of developing hamstring strength under these conditions. High-intensity eccentric loading of the hamstring muscles is also proven to elicit morphological changes (5). Architectural changes such as increased fascicle length is known to increase the amount of force tolerated through the muscle during high-intensity activities (44). With this understanding and with the high eccentric forces recorded in this study, using assistive loads or performing the NHE could promote positive architectural changes to the hamstrings. Overall our results are favourable to the use of assisted NHE because individuals are able produce high eccentric forces that are considered to improve hamstring architecture and the tolerance of load through the hamstring muscles (5,44).

Both BF and ST activation, were not significantly reduced by the assisted conditions. There were no significant differences observed between the BF and ST muscles across each loading condition either. The BF was activated to between 65 and 90% MVIC and the ST activated between 65 and 81% MVIC. Tsakilis et al. (45) reported BF sEMG activity during the NHE at around 60% of MVIC with ST exceeding BF in sEMG response among female track athletes. Bourne et al. (8) reported BF sEMG activity at ~75% MVIC and ST sEMG at ~100% MVIC among males. The sEMG analysis in this study showed that relative to MVIC activity, all conditions of the NHE demonstrate a moderate-to-high intensity of hamstring activity in agreement with previous studies. Because fatigue is known to increase the amplitude of sEMG signal, the prolonged duration of the NHE in this study (5s) along with the increasing load of the movement may have elicited a fatigue response and invariably a moderate-to-high sEMG amplitude across all conditions (21,28,37). Previously, the ST is reported as more active in comparison to the BF and is likely due to the superior amount of plane moment attained by the muscle in knee flexion tasks compared to the BF and SM (8,29,41). Our data may reflect the level of hamstring development of our population sample, or it indicates a different neuromuscular activation pattern as a result of the isotonic assistance provided by the Keiser^{TM} functional trainer.

There was no trend to suggest that increasing the assistive load would change the ratio of BF to ST activity showing that assistive load does not change activation balance of hamstring muscles. This finding is different to that suggested by Bourne (8) in which the ST is preferentially recruited during the NHE. Ono et al. (33) reported trivial differences between the activation patterns of an eccentric hamstring exercise utilizing knee flexion on a plate loaded machine. McAllister et al. (27) measured posterior-chain sEMG activity during hamstring dominated exercises and found the ST to be activate more than the BF during the NHE. Interestingly, Higashihara, Ono, Kubota and Fukubayashi (22) measured sEMG activity during eccentric isokinetic knee flexion at different speeds (10-300 °·s). The authors found that irrespective of angular velocity there was no significant difference between hamstring muscle activation until the final 15-degree epoch of extension where the BF activated significantly less. The variance in sEMG activity observed in previous research during eccentric knee flexion would suggest that the findings of the current study are not untoward. It could be inferred from our findings that performing the assisted or unassisted NHE promotes BF activation more so than previously reported. This is an important point when considering the high injury risk to the BF among soccer players (17). However, we acknowledge the low-to-moderate statistical power attained during the analysis of the sEMG data. Future research specifically focusing only on hamstring muscle activation during the NHE should look to recruit and analyse a greater sample size and perhaps other methods of muscle activation analysis.

This was the first study to measure the output of the assisted NHE using the 10-point Borg similar to how Morishita et al. (32) quantified resistance training load. Our data indicate that the difficulty and intensity of the NHE is affected by assisting the exercise. Participant RPE was significantly reduced between all assisted conditions and the unsupported condition in agreement with previous research, showing a strong relationship between external training load and RPE (12,31). Additionally, de Morree et al. (14) proved how effort perception correlates with central motor command and that perceived effort can limit movement execution. Therefore, RPE appears useful to quantify or assess the intensity of the assisted NHE.

There are some limitations to this study that should be considered when investigating the assisted NHE in future. For example, only the dominant limb was assessed in this investigation whereas future research could make cross-limb comparisons with the changing level of assisting load. In future studies, considering the amplitude and speed of the movement, measuring impulse and sEMG at different joint angle portions may also offer a better insight to the eccentric forces and muscle activation patterns elicited during the NHE. Indeed, Higashihara et al. (22) have indicated that knee flexor torque (in turn it is likely to be true also for muscle activation) is affected by higher angular velocities and monitoring this would add greater experimental control. There are also limitations to using sEMG particularly the cross talk of signals between muscles meaning that signal from individual muscles cannot be reliably identified (18). Also, it is well known that sEMG can present large variability in readings as exampled in the sEMG results of this study (see Figure 5) and this could have affected the statistical analysis of our findings. With this in mind, functional magnetic resonance imaging which identifies the metabolic changes within individual muscles following exercise, should be utilised in future investigations (7). This would also allow researchers to assess architectural changes to the hamstrings either acutely or over a training period. In addition, future investigations should assess what fatiguing effects performing such a volume may have on athletes by recording the soreness experienced by participants in time periods following data collection. Similarly, participants should be blinded from knowing what assisting loads they are using in order to avoid pre-estimation of RPE according to the load. Finally, data collection was conducted at different times of the training day due to logistical constraints. This may have impacted the amplitude of sEMG signals, knee flexor strength and RPE (25,35). Future investigations should correct this by conducting data collecting at the same point in the training week and at the same time in the training day.

PRACTICAL APPLICATIONS

This study supports the inclusion of the assisted NHE in strength training and injury reduction programmes. Assistive load from cable machines, particularly those that use pneumatic resistance, can alter the intensity of the exercise significantly. Strength and conditioning coaches should prescribe assistive loads to manipulate training volume and intensity. Assistive loads can be used to progress the NHE towards higher intensities either within a single session or over a training period which could be useful for youth or weaker athletes. Athletes may respond more positively to the assisted NHE as the perceived effort to perform the exercise may limit execution, and this can be reduced or increased as required with assistive loads. Furthermore, higher eccentric knee flexor force is known to drive architectural adaptations and assisting loads would allow for better fascicle lengthening during the exercise as the tempo of the movement can be controlled optimally (7). Finally, the assisted and unassisted NHE do not favour activation of the BF or ST and elicit moderate-to-high hamstring activation across loading conditions. Therefore, individuals can train at a perceived lower intensity when using assistive loads and still attain relatively high hamstring muscle activation.

Disclosure of funding:

No funding received.

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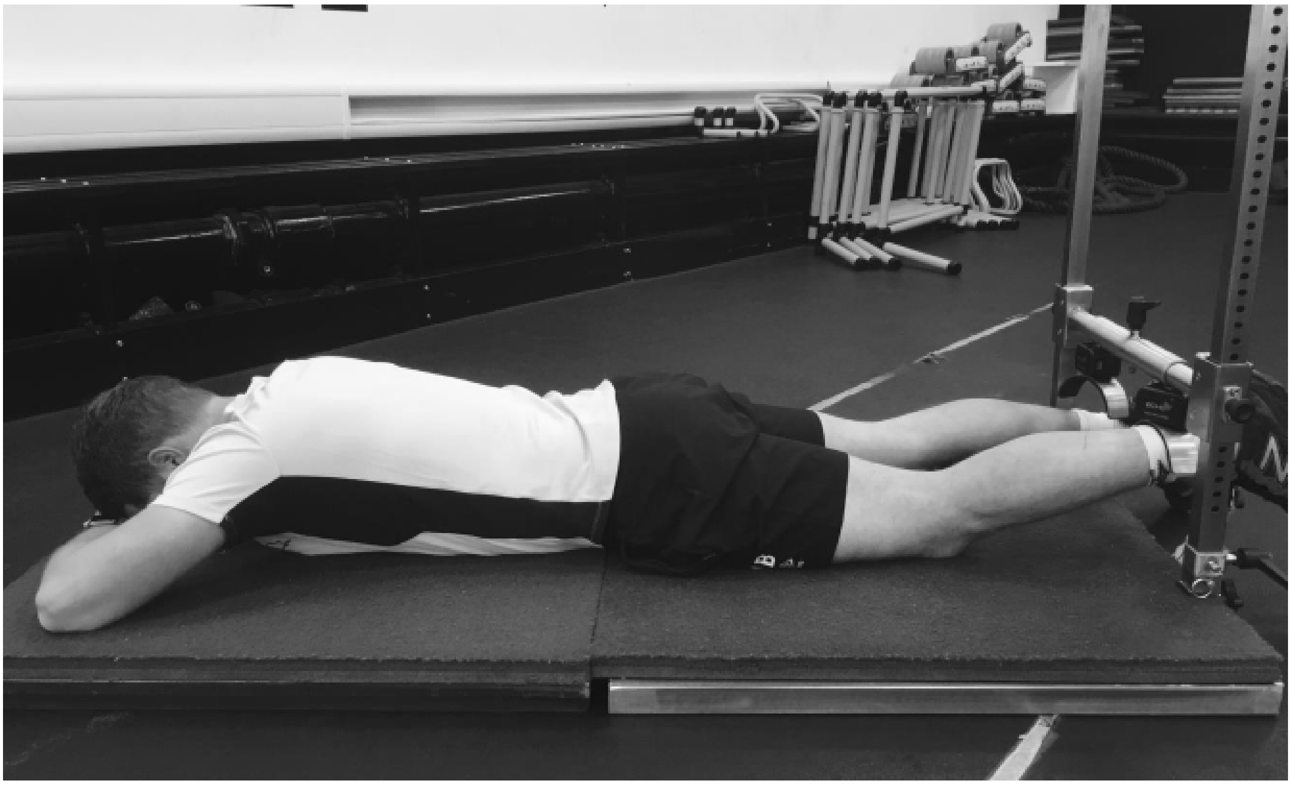

Figure 1. Example of unilateral MVIC performing knee flexion at 160° in prone position with the hips at 0° flexion against an isometric dynamometry system.

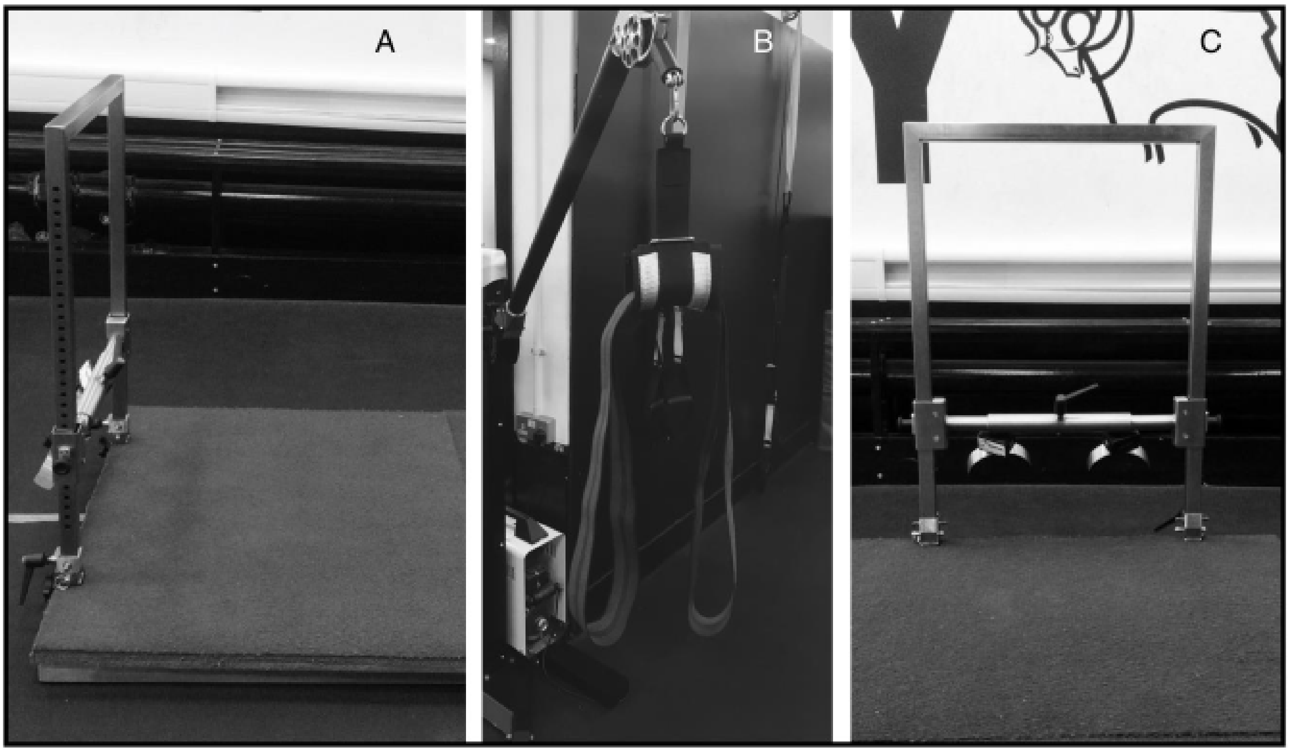

Figure 2a-c. a: Metal-framed rig used to attach static force gauge to; b: Attachment used to connect the participant to the Keiser^{TM} functional trainer; c: Custom made attachments used with static force gauge.

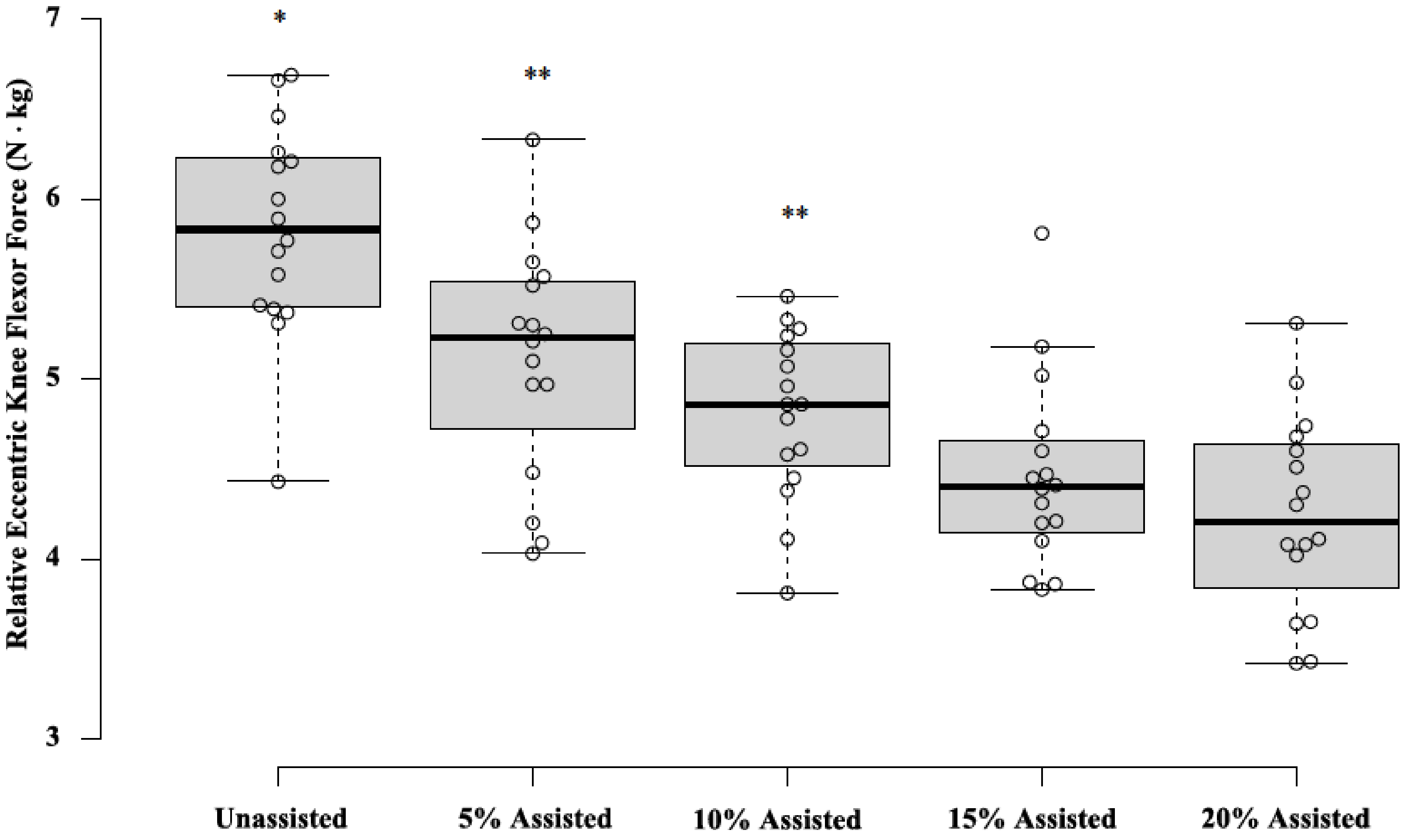

Figure 3. Relative eccentric knee flexor force (N·kg) during the Nordic hamstring exercise using different assisting loads. Peak eccentric knee flexor force measured during each repetition of the NHE was normalised relative to participant mass. *$p < 0.05$ from 5, 10, 15 and 20% assisted conditions. **$p < 0.05$ from 15 and 20% assisted conditions. Centre lines show the medians; box limits indicate the 25th and 75th percentiles as determined by R software; whiskers extend 1.5 times the interquartile range from the 25th and 75th percentiles, outliers are represented by dots. n = 16 sample points.

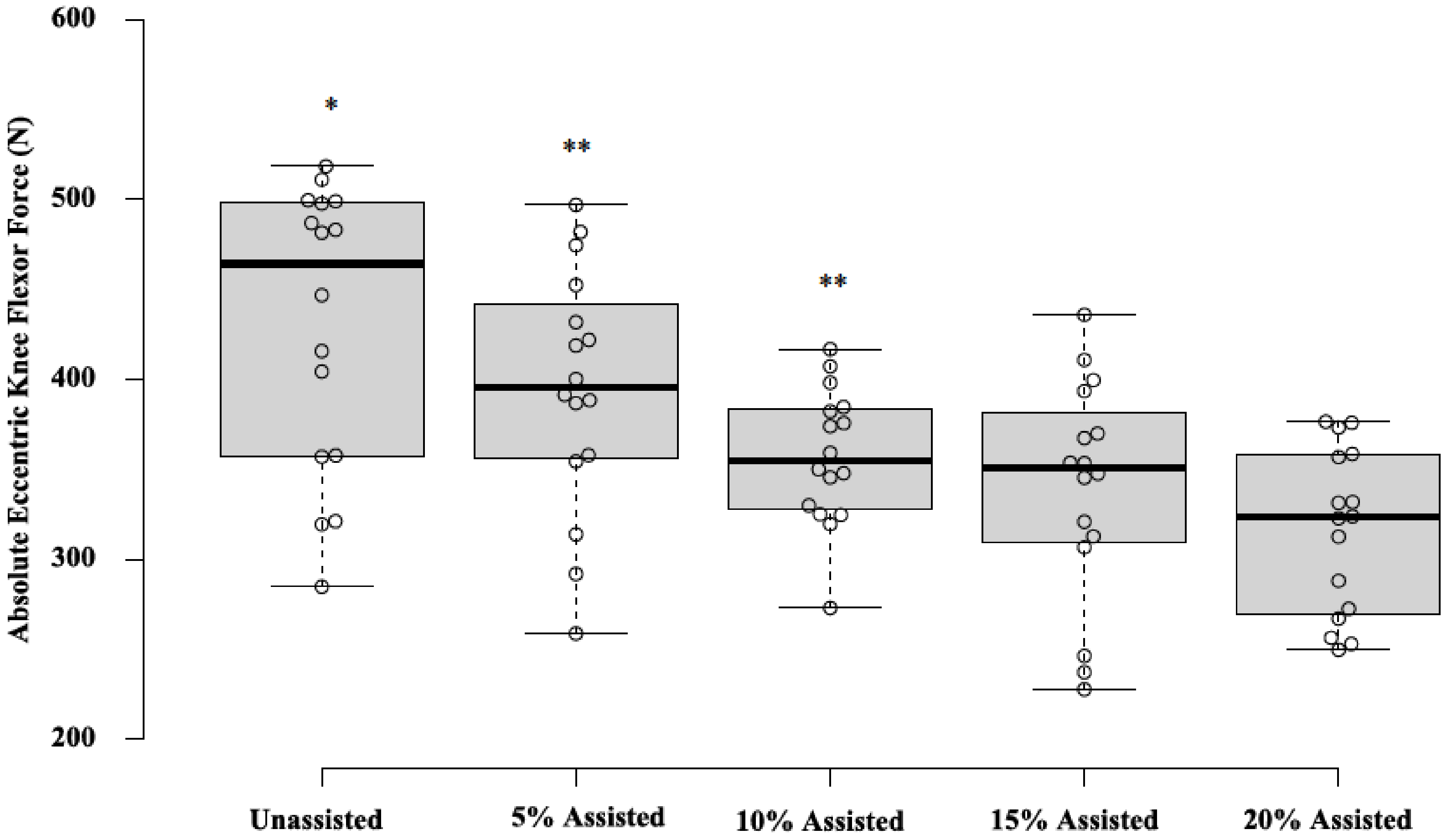

Figure 4. Absolute eccentric knee flexor force (N) during the Nordic hamstring exercise using different assisting loads. Measures of force represent the peak absolute force measured during the NHE. *$p < 0.05$ from 5, 10, 15 and 20% assisted conditions. **$p < 0.05$ from 15 and 20% assisted conditions.

Centre lines show the medians; box limits indicate the 25th and 75th percentiles as determined by R software; whiskers extend 1.5 times the interquartile range from the 25th and 75th percentiles, outliers are represented by dots. n = 16 sample points.

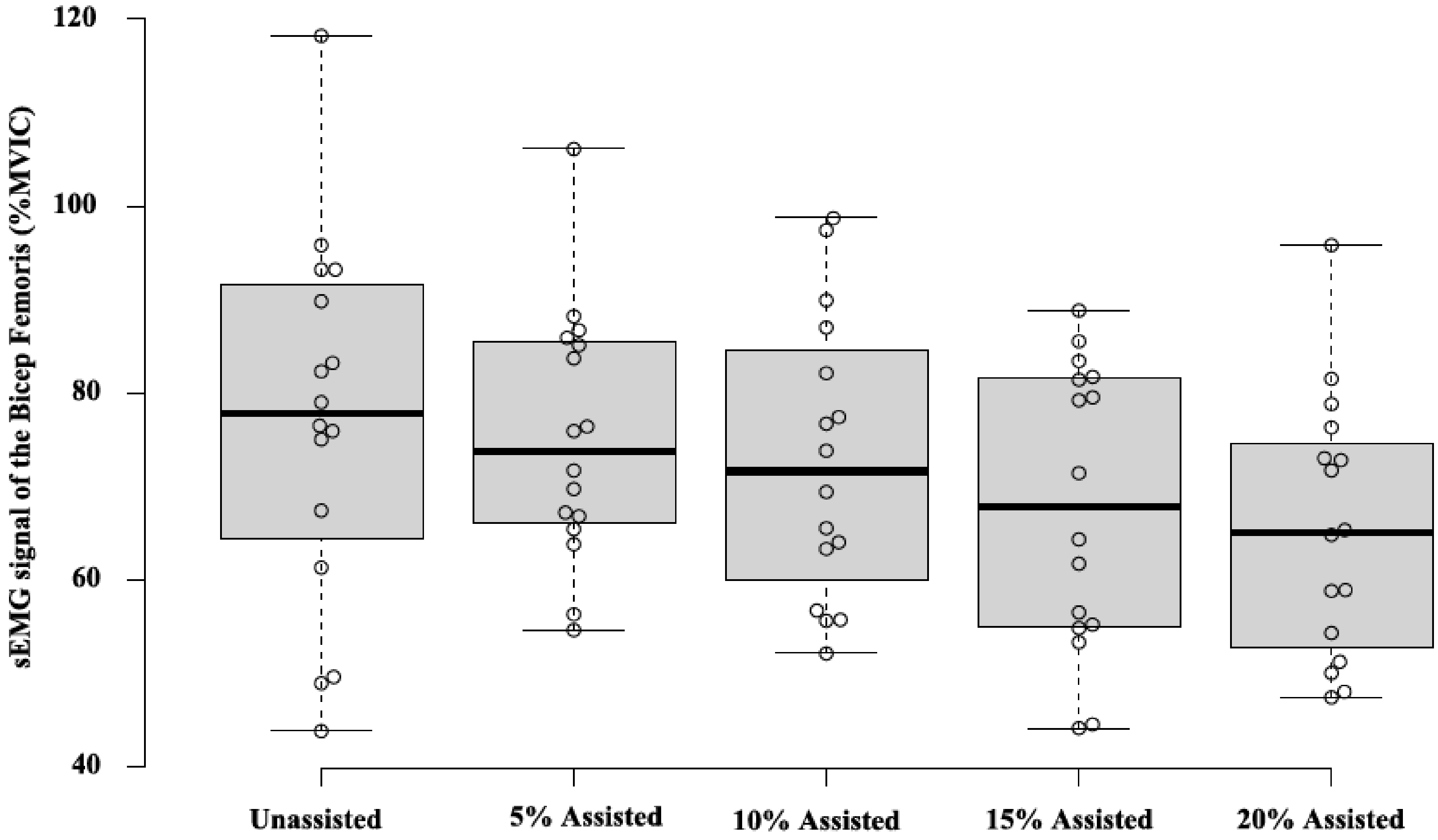

Figure 5. BF: Peak RMS sEMG signal for the biceps femoris (BF) when performing the Nordic hamstring exercise using different assisting loads. Centre lines show the medians; box limits indicate the 25th and 75th percentiles as determined by R software; whiskers extend 1.5 times the interquartile range from the 25th and 75th percentiles, outliers are represented by dots. n = 16 sample points.

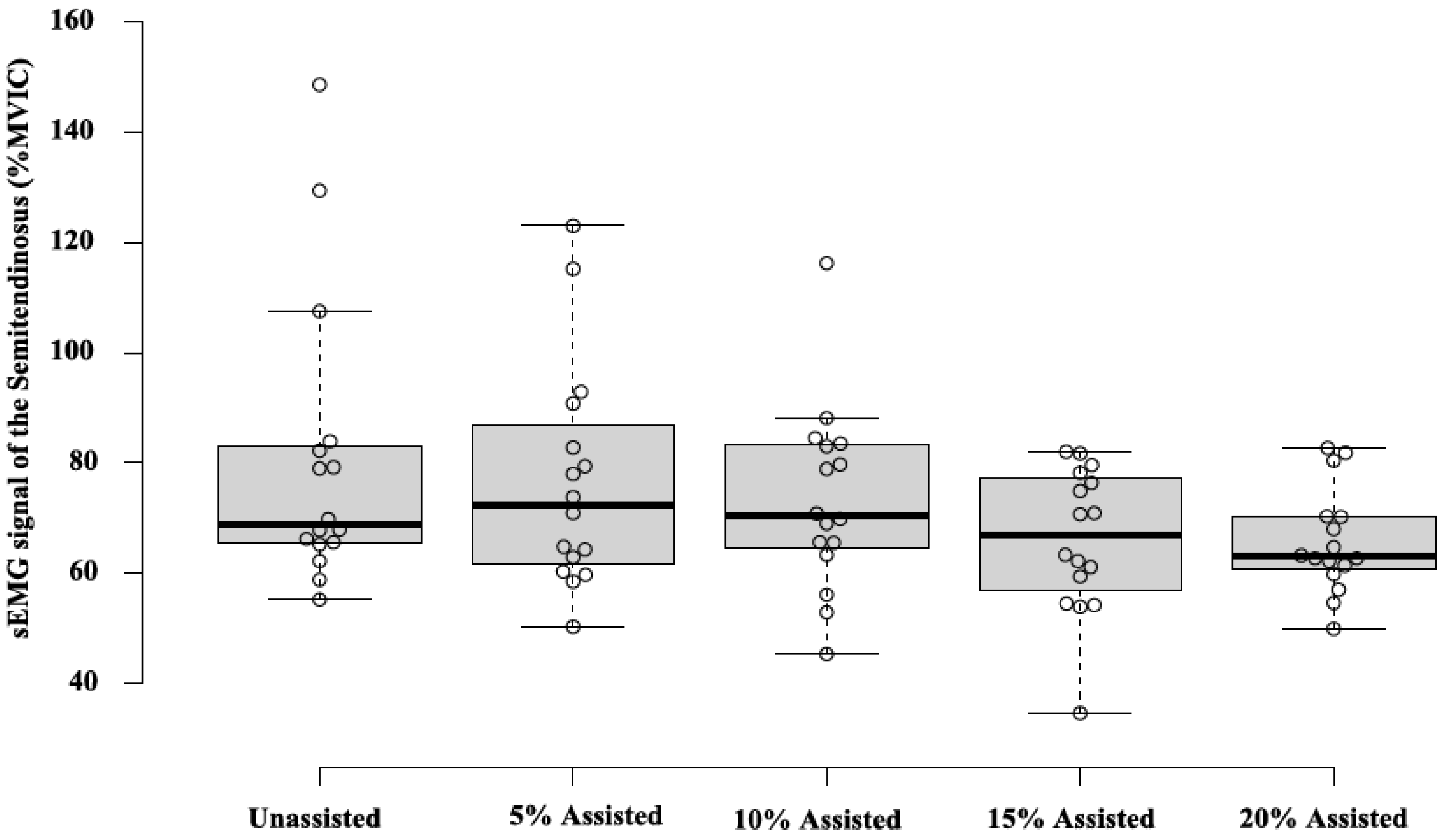

Figure 5. ST: Peak RMS sEMG signal for the semitendinosus (ST) when performing the Nordic hamstring exercise using different assisting loads. Centre lines show the medians; box limits indicate the 25th and 75th percentiles as determined by R software; whiskers extend 1.5 times the interquartile range from the 25th and 75th percentiles, outliers are represented by dots. n = 16 sample points.

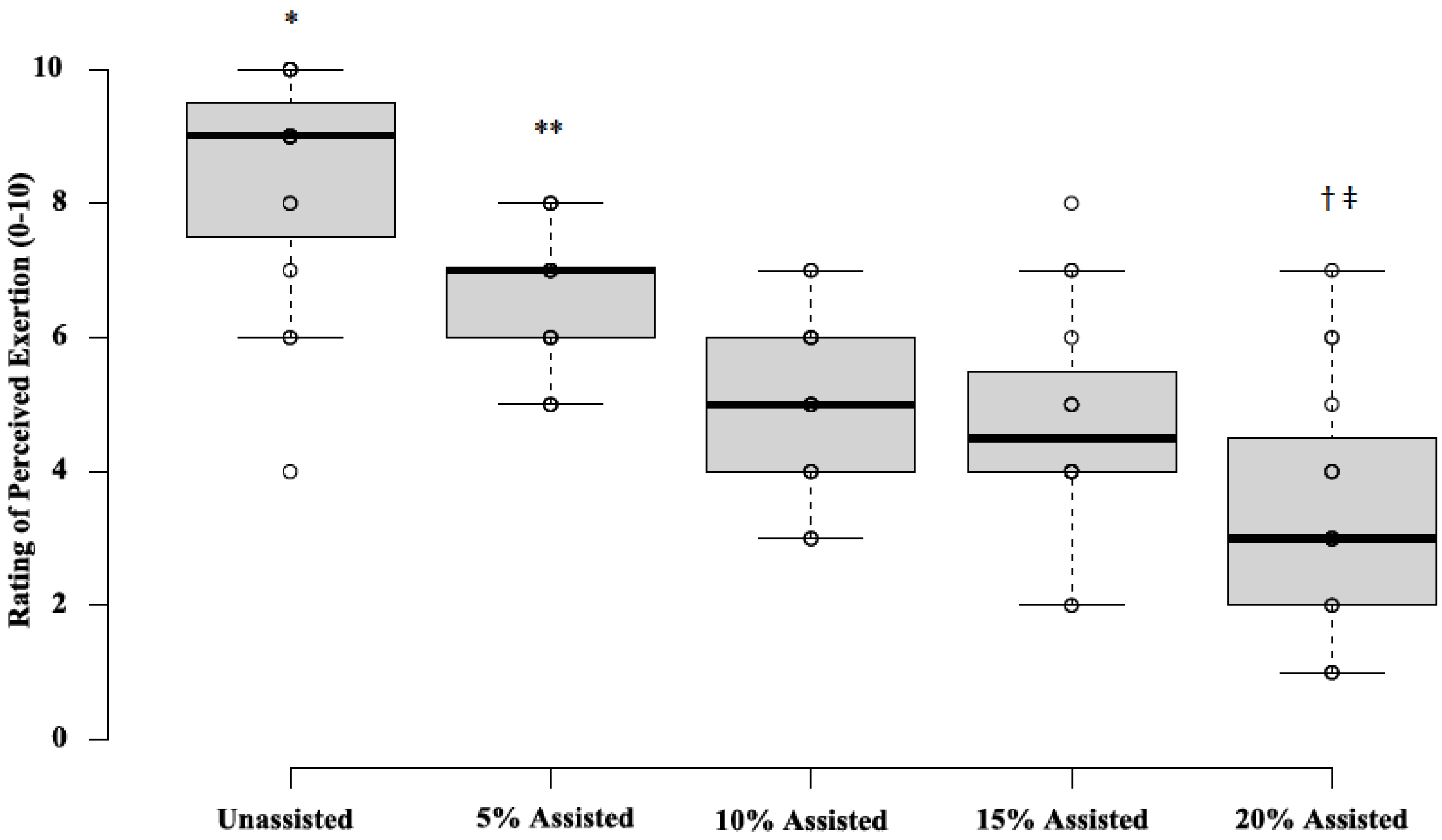

Figure 6. Rating of perceived exertion (scale 0-10) after performing three reps of the Nordic hamstring exercise using different assisting loads. *$p < 0.05$ from 5, 10, 15 and 20% assisted conditions. **$p < 0.05$ from 10, 15 and 20% assisted conditions. †$p < 0.05$ from 10% assisted conditions. ‡$p < 0.05$ from 10% assisted conditions. Centre lines show the medians; box limits indicate the 25th and 75th percentiles as determined by R software; whiskers extend 1.5 times the interquartile range from the 25th and 75th percentiles, outliers are represented by dots. n = 16 sample points.

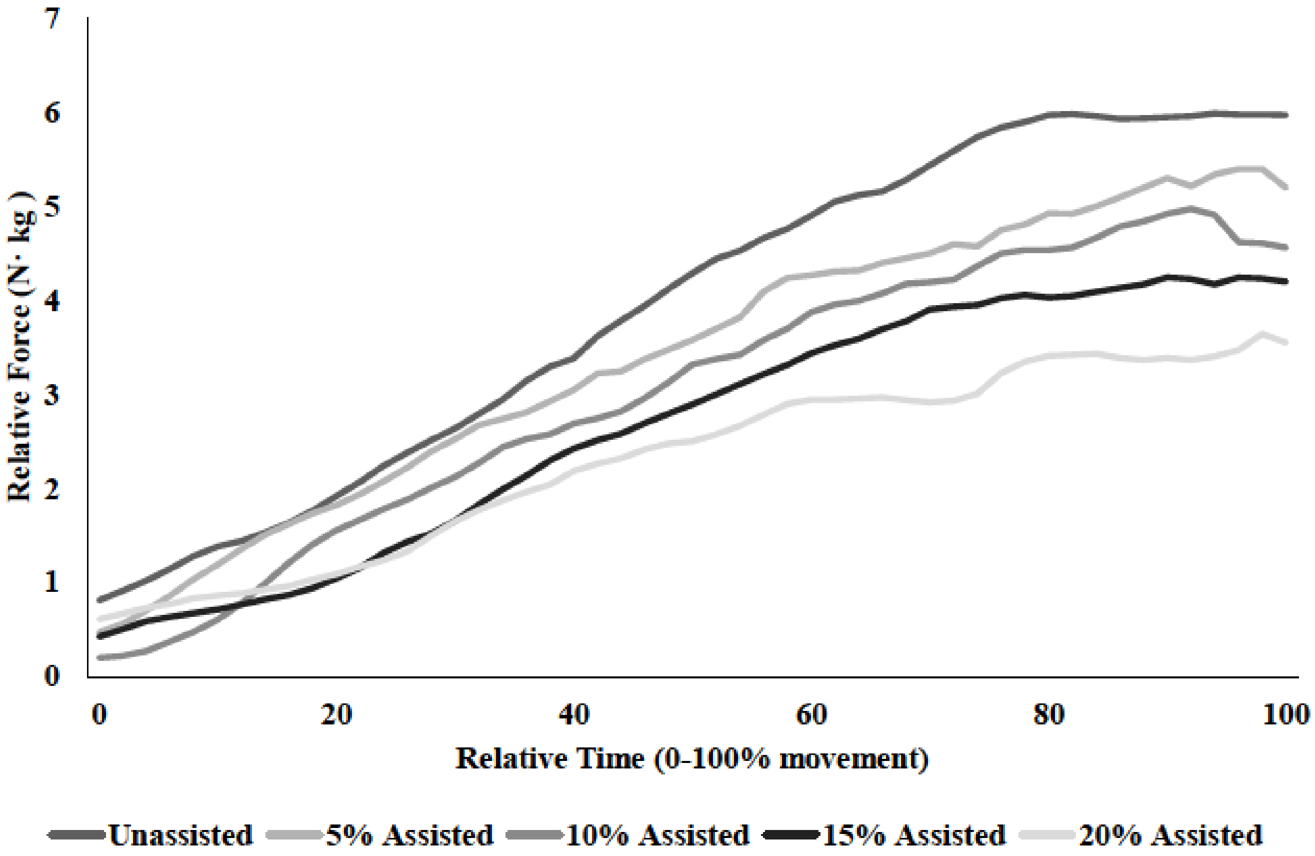

Figure 7. Example of force-time traces of knee flexor strength measured while using assisted and unassisted conditions.

Table 1. Description of Warm Up Protocols

Stage	**Exercise**	**Description**	**Rest**
Raise	Cycling	5-minutes of cycling at a moderate intensity (90 RPM, Medium Resistance).	60s
Activation	Bilateral Bridge	1 x 10 reps	20s
	Single-Leg Bridge	1 x 10 reps	20s
	Hamstring Walks	1 x 30s	20s
	High Box Bridge	1 x 10 reps each leg	20s
	Single-Leg Bridge Slides	1 x 5 reps each leg	60s
Potentiation	Iso-Prone	Two submaximal reps (60 and 80% perceived effort) followed by two recorded maximal reps for 5-seconds in duration. Each rep is separated by 15-seconds rest.	-

Table 2. Biceps Femoris to Semitendinosus ratio of left and right limbs (± *SD*) under different conditions of the assisted NHE.

Loading Condition	**BF: ST**
Unassisted	1.01 (0.32)
5% Assisted	1.03 (0.29)
10% Assisted	1.03 0.27)
15% Assisted	1.06 (0.30)
20% Assisted	1.01 (0.24)

Table 3. Mean knee flexor strength measures relative to the unassisted NHE.

Loading Condition	**Relative Knee Flexor Strength (% of unassisted NHE)**
Unassisted	100.0%
5% Assisted	91.9%
10% Assisted	83.0%
15% Assisted	78.9%
20% Assisted	73.4%