Examining the effect of verbal feedback vs. real-time software feedback on kinetic and kinematic metrics of the Nordic hamstring exercise

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RESEARCH

Examining the effect of verbal feedback vs. real-time software feedback on kinetic and kinematic metrics of the Nordic hamstring exercise

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Abstract

Purpose A wealth of research exists for the Nordic hamstring exercise and several devices provide real-time feedback on torque profiling. However, none currently offer feedback on technique execution. This study investigated the effect of verbal and software feedback on Nordic exercise kinetic and kinematic metrics.

Methods 24 recreational participants completed two sets of three bilateral repetitions on a hamstring testing device. In a crossover design, one set was performed with verbal feedback, while the other set used software-based feedback. Hamstring strain injury risk metrics (peak torque, break-torque angle, and bilateral limb percentage difference) and exercise technique metrics (relative trunk-to-thigh angle and angular velocity of the knee) were recorded for analysis.

Results The feedback type significantly affected eccentric knee flexor peak torque, by a mean decrease of 7.1 Nm when performed with software feedback (Cohen's $d = 0.238$, $p < 0.01$). Altering feedback had no significant effect on bilateral limb difference percentage (Cohen's $d = 0.068$, $p = 0.578$) or break-torque angle (Cohen's $d = 0.159$, $p = 0.115$). Software feedback significantly decreased the mean of both the relative-trunk-to-thigh angle at peak torque by 5.7° (Cohen's $d = 0.514$, $p < 0.01$) and the angular velocity of the knee at peak torque by 8.7 $deg \cdot s^{-1}$.

Conclusions An integrated software feedback system significantly improves acute Nordic exercise technique, benefitting individuals initially exhibiting poorer technique the most.

Keywords Nordic hamstring exercise · Software feedback · Technique

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Abbreviations

AVK	Angular velocity of the knee joint
BFlh	Biceps femoris long head
BLD	Bilateral limb difference
BTA	Break-torque angle
HSI	Hamstring strain injury
NHE	Nordic hamstring exercise
RTA	Relative trunk-to-thigh angle
SF	Software feedback
TUT	Time-under-tension
VF	Verbal feedback

Introduction

A conventional Nordic hamstring exercise (NHE) is performed with an athlete assuming a kneeling start position, with the hips fully extended and the torso held upright and rigid [1]. From this position, the athletes perform a controlled forward rotation action about the knee. In the majority of studies, the athletes are informed to gradually lean forward at the slowest possible speed, maximally resisting the forward-falling movement with both legs, whilst holding the hips fixed in line with the knee and shoulder joints throughout the range of movement, keeping a neutral position throughout [1–4]. The factors affecting the quality of an NHE trial include having a distinct peak torque, maintaining a neutral hip flexion angle and performing a controlled descent speed [5, 6]. Previous work by Sconce et al. [7] reported poor overall NHE exercise technique and high intrasubject variability for both relative trunk-to-thigh angle at peak-torque (RTA) (*range* = 0.4–44.7°), and angular velocity of the knee at peak-torque (AVK) (*range* = 3.6–93.4 deg·s^{-1}) in 127 NHE trials ($n = 18$). Poor NHE technique can be problematic as excessive hip flexion produces larger NHE torque values at the same knee angle compared to a neutral hip position, which can lead to unreliable results between groups. Hip flexion during the NHE increases the lever arm of the centre of mass about the knee joint axis, which shifts the load onto the knee flexors at longer muscle lengths, potentially moving the torque-generation capacity towards the descending limb of the force–length curve [8, 9]. Therefore, the hip flexion angle should be controlled to allow accurate comparison between athletes [10]. Increasing hip flexion lengthens hamstring musculature, as observed in razor curl training [11], however, this exercise does not exhibit a measurable break-point, which is required for assessing the length of the muscle at which failure occurs. A controlled NHE descent, characterised by maintaining a constant angular velocity and avoiding 'breaking' at the hip, ensures that the torques at both the hip and knee are balanced at a given knee angle. Conversely, a rapid increase in hip angular acceleration (or hip 'breaking') can shift the load away from the knee flexors, thereby reducing the torque required to maintain or achieve a specific knee angle.

In the current literature, NHE descent speed has generally been assessed visually and enforced through verbal instruction using a very slow approach throughout the active range of motion (ROM) or descending to an average cadence of 30 deg·s^{-1} using a metronome [12–15]. AVK influences resultant torque, due to a shift of the torque–velocity relationship and also results in less time for the knee flexors to decelerate and control the forward action. This reduces time-under tension (TUT) which is important in NHE training for hypertrophy, specific muscle fibre recruitment, muscular endurance, metabolic stress, and motor unit activation [16]. A controlled descent ensuring a maximal break-point is important for determining accurate muscle torque-length capabilities of the knee flexors, such as break-torque angle (BTA). A controlled descent should promote recruitment of the hamstring muscle complex, minimising the activity of the accessory muscles such as the gluteus maximus, gastrocnemius, erector spinae, and adductors as suggested by Sconce et al. [7]. However, further targeted studies are needed to confirm this reduction in compensatory muscle activity. Furthermore, as suggested by Alt and Schmidt [5] poor NHE execution may impede or even prevent adaptations at long hamstring muscle lengths occurring at extended knee angles.

Few studies have considered exercise technique whilst performing the NHE. Alt and Schmidt [5] have proposed clear NHE training execution quality criteria (ANHEQ), recommending that NHEs should be executed with a constant knee extension velocity of 15 deg·s^{-1} across the largest possible knee ROM (in a supramaximal unassisted NHE this would be up until 'break-point') with a suggested time under tension of ~ 6.5 s per repetition. Moreover, they propose the eccentric phase of the NHE should be performed with minimal hip flexion, keeping the hands situated close to the shoulders, which is typical in the majority of the research [2, 14, 17–19]. This provides useful recommendation targets for NHE-assisted training; however, as found by Sconce et al. [20] is difficult to implement for supramaximal NHE testing. We propose that integrating a software feedback system for testing can standardise NHE trials [21]. Moreover, controlling RTA and AVK (up until break-point) will provide consistent data, ensuring injury risk metrics (eccentric knee flexor peak torque and BTA) can be reliably reproduced between groups of athletes.

It is well recognised that performance can be improved by augmented feedback (feedback from an external source provided as knowledge of performance or result) [22, 23]. This type of feedback is often used during resistance training to enhance acute physical performance and has shown promise as a method for improving chronic physical adaptation [24–27]. The application of feedback helps increase the rate of learning which may reduce some injury risk factors [21]. For example, verbal feedback has been shown to significantly increase eccentric knee flexion force output when traditionally measured on isokinetic dynamometry [28, 29]. Most current hamstring testing and training devices offer some kinetic 'visual' feedback in the form of live graphical representation of force or torque traces using integrated dashboard software for performance metrics [30–32]. However, most NHE studies have only used verbal researcher encouragement or a metronome to control NHE technique such as hip flexion and descent speed, rather than specific computer feedback. Few studies have used visual feedback [13, 21, 33, 34], and very limited studies [21, 27] have studied the effect of feedback on NHE metrics, and none to our knowledge examining the effect of *both* kinetic and kinematic feedback on NHE exercise '*technique*' metrics. Alt and Schmidt [5] state that for NHE intervention studies, standard training procedures should specify a constant target movement speed to obtain reliable results and it is recommended to use a monitor to provide angle-time information in real-time to participants. This study aims to develop a novel, robust visual feedback NHE execution technique system and examine its effect on injury risk and technique metrics. The objective is to integrate a software system within the existing HA*L*HAM° device [7] to monitor hip position and knee extension speed. It is hypothesised that software feedback will improve exercise technique.

Methods

Participants

Twenty-four recreationally active participants ($n = 24$) of varying NHE training experience, gender, and age were recruited to participate in this study (Mean ± SD age 29 + 11 years, height 177 ± 8.3 cm, and body mass 78.6 ± 14.1 kg). With exercise technique being the feedback focus, and this being explanatory research, a diverse representation of participants was chosen to offer a more holistic understanding of technique challenges and the impact of feedback. All participants completed an initial questionnaire, used to gather data medical and injury data. Exclusion criteria included a lower extremity injury in the previous 6 months requiring medical intervention or that caused significant functional impairment. The participants were also excluded if they reported a history of recurrent low-back, hip, thigh, or knee injuries. This refers to multiple episodes of an injury, including any injuries that restricted physical activity or pain during exercise for more than 2 consecutive weeks on 2 or more occasions within the last 6 months. Furthermore, all participants self-declared as being physically fit and free from any health or medical conditions that would contraindicate or impede them from performing maximal NHE testing. After having all procedures explained to them, participants provided written informed consent to participate in the spirit of the Helsinki Declaration, before testing commenced. The ethical approval for the study was approved by the Universities Ethics Committee (ER29609708).

Experimental protocol/design

The HA*L*HAM° NHE custom device developed by Sconce et al. [7, 20] was used to collect the data. Strain gauge load cells (DYMH-103 Micro Miniature Load Cell) measured individual right and left limb forces and the software displayed these and combined limb total forces as force–time traces in line graph format. The torque was calculated for each NHE trial from the force measured by the load cells and the distance measured from the set pivot point (0.661 m). The participants' NHE starting position was determined by lining up the lateral femoral epicondyle of the femur with the pivot point before commencement [7]. An IMU (MOT1101_0, Phidgets Inc, Calgary, Canada) was positioned on a custom-made plastic carrier with pointed ends to help align the sensor laterally on the upper leg at an equal distance away from the greater trochanter and lateral femoral epicondyle. The IMU trunk sensor was also positioned laterally at an equal distance from the greater trochanter to the shoulder bursa. The IMU device had a data acquisition rate of 41.67 Hz. The pilot work was conducted to assess the level of agreement between a Liberty® Polhemus system (Colchester, Vermont, USA) and the integrated IMU system of the HA*L*HAM° to determine angular metrics. Very strong correlations (near perfect) were observed ($n = 25$ trials) for relative thigh break-angle, relative trunk break angle, and relative trunk-to-thigh angle at break-point when measured by Polhemus (gold standard measure) and then determined through IMUs respectively ($r = 0.99$, $p < 0.0001$; $r = 0.99$, $p < 0.0001$; $r = 0.99$, $p < 0.0001$).

For the verbal feedback (VF) condition the researcher instructed participants to gradually lean forward at the slowest possible speed maintaining a neutral trunk alignment with the hips fixed in line with the knee and shoulder joints [2], whilst holding the hands in line with the shoulders, palms facing forward. The avoidance of hyperextension was advised. The participants were asked to perform the Nordic action until they could no longer withstand the torque around their knee flexors, using their hands to buffer the fall onto a fixed platform [1, 4]. The software feedback (SF) was a custom-made visual system using an on-screen mannequin representation of a person and a pre-determined reference line to provide visual cues for the user (Fig. 1). The IMU sensors tracked the user's knee and hip flexion angles in real time and used these to animate the mannequin. The superimposed dynamic reference line extended from the mannequin's lateral epicondyle through the greater trochanter, to the shoulder bursa. Speed was set at 20 deg·s^{-1} which was determined from previous work [7, 20] and is

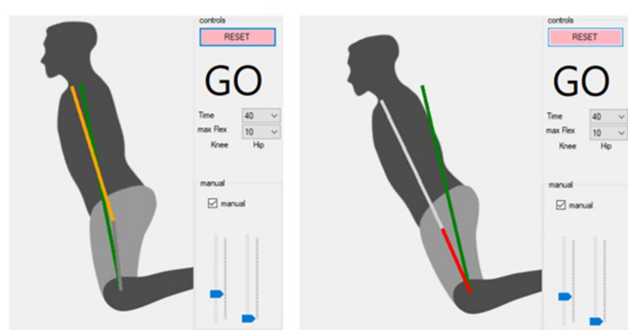

Fig. 1 Custom-made visual feedback system, and on-screen mannequin with reference line. The moving reference line turns orange (**a**) as a warning if within a range of 5° and then red if greater than 5° from the set coordinates

comparative to the NHE velocity used in the literature [34, 35]. Hip flexion was set at 0° to encourage a neutral position throughout the range of motion. As the user performed the NHE action, they were prompted to match the movement of the reference line with the virtual representation on-screen. A monitor was positioned on a stand on the floor, at the base of the HA*L*HAM° platform to suit the eye-line position. The grey reference line warned the user of deviation from the set optimal hip angle and speed by turning orange as a warning if within a range of 5° and then red if greater than 5° from the set coordinates (Fig. 1).

Raw IMU data were acquired on a personal computer via a Phidget Bridge data acquisition board (Phidgets Inc., Calgary, Canada). The IMU data were converted into angles using a custom-coded programme implementing a complementary filter and then exported in.CSV format. Using MATLAB R2020b software (MathWorks, Inc., Natick, MA) the following variables were subsequently calculated using a custom script:

Injury risk metrics as proposed in our previous work [20]:

- *Peak torque* ~ NHE bilateral maximum torque value (calculated by summing the peak torque recorded for each limb)
- *Break-torque angle* (BTA) ~ representing the knee and corresponding thigh angle at the instant that peak torque occurred. The full extension is represented as 180 degrees.
- *Bilateral limb torque difference* (BLD) ~ representing the percentage difference between the right and left leg maximum torque values.

Exercise technique metrics as proposed in Sconce et al. [20]:

- *Relative trunk-to-thigh angle* (RTA) ~ the angle in the sagittal plane between the thigh and the trunk throughout the NHE ROM, representing hip angle. RTA at peak torque was then determined. A higher RTA value corresponds to a greater degree of hip flexion, while a lower value indicates a more neutral position.
- *Angular velocity of the knee joint* (AVK) ~ representing the angular velocity of the knee joint throughout the NHE ROM, filtered using an 11-point average. AVK at peak torque was then determined.

Trials

Prior to performing the trials participants were instructed to perform an individual warm-up by using a stationary bike or rower for 3–5 min and completing dynamic movements such as arm and hip circles, leg swings, heel-to-toe walks, knee hugs, walking lunges, and squats (two sets of ten repetitions). A crossover randomised design was used so that all participants received verbal instruction *and* real-time software feedback on NHE technique over two separate sets of three maximal repetitions (six maximal repetitions overall). The rest period between repetitions was long enough to allow the participant to comfortably recover for the next maximal effort and was advised as ~ 6 s [5]. The rest period between feedback types was substantial, at least 15 min, allowing for complete recovery. The order of performing the feedback (either VF or SF first) was randomised between participants.

Statistical analysis

144 trials from 24 participants ($n = 24$) were initially considered (72 trials for each feedback condition). Data from the HA*L*HAM° IMU's were treated in MATLAB R2020b software (MathWorks, Inc., Natick, MA) and the data were subsequently statistically processed in GraphPad Prism 8.43 (GraphPad Software Inc). The trial exclusion criteria were no clear peak in the force–time trace, an extended flattened period, or no clear torque drop-off period; no trials were rejected. The descriptive statistics for all trials were calculated and reported as mean ± standard deviation (Table 1). Normality of data was confirmed using an appropriate test (Shapiro–Wilk) and a visual check of a Quantile–Quantile plot. The average of each participant's three trials was calculated and multiple independent t-tests were performed to compare differences in each metric between feedback conditions (VF and SF). The metrics compared were peak eccentric knee flexor torque (Nm), BTA (°), BLA (%), RTA (°) at peak torque, and AVK (deg·s^{-1}) at peak torque. Where appropriate, effect sizes were calculated by Cohen d and interpreted as small ($d \geq 0.2$), moderate ($d \geq 0.5$), and large ($d \geq 0.8$) [36].

Results

Injury risk factor metrics

Changes in mean peak torque, BLD, and BTA with feedback type can be seen in Table 1 and Fig. 2. Feedback type significantly affected eccentric knee flexor peak torque ($d = 0.238$ (*Small*), $p < 0.01$) which lowered when the NHE was performed with SF showing a mean decrease of 7.1 Nm compared to VF. Altering feedback had no significant effect on BLD ($d = 0.068$, $p = 0.578$) or BTA ($d = 0.159$, $p = 0.115$).

Exercise technique metrics

RTA and AVK changes with feedback can be seen in Table 1 and Fig. 3 RTA significantly decreased with SF ($d = 0.514$

Table 1 Mean ± SD and range reported for each metric per feedback condition ($n = 24$)

Metrics	Verbal feedback		Software feedback	
	Mean ± SD	Range (Min–Max)	Mean ± SD	Range (Min–Max)
Kinetics				
Peak torque (Nm)	79.7 ± 31.4*[a]	32.7–148.4	72.6 ± 27.9*[a]	36.2–142.1
Kinematics				
BLD (%)	10.8 ± 6.4	2.9–30.6	11.2 ± 6.5	4.2–29.9
BTA (°)	118.8 ± 9.8	102.0–141.3	120.3 ± 9.1	106.5–146.2
RTA (°) at peak-torque	22.1 ± 13.2*[b]	1.7–57.9	16.4 ± 8.7*[b]	2.3–34.6
AVK ($deg{\cdot}s^{-1}$) at peak-torque	24.6 ± 13.5*[c]	5.8–61.6	15.9 ± 5.9*[c]	3.5–26.7

Nm Newton-metre, % percentage difference, ° degrees, $deg{\cdot}s^{-1}$ degrees per second

BLD Bilateral limb torque difference, *BTA* Break-torque angle, *RTA* Relative trunk-to-thigh angle, *AVK* Angular velocity of the knee

*Denotes a significant difference between VF and SF ($p < 0.01$)

[a]denotes a small effect size

[b]Denotes medium effect size

[c]Denotes large effect size

(*Moderate*), p < 0.01) showing a mean decrease of 5.7° compared to VF. AVK significantly decreased with SF ($d = 0.825$ (*Large*), $p < 0.01$) showing a mean decrease of 8.7 $deg{\cdot}s^{-1}$ compared to VF.

Discussion

The findings affirm the hypothesis that SF enhances acute NHE exercise quality, agreeing with the systematic review findings by Weakley et al. [37]. They reported that resistance training feedback has a positive influence on immediate performance and can improve favourable adaptations over the long term. Both technique metrics significantly improved (Table 1 and Fig. 3); however, performance metrics demonstrated either no significant change or a negatively impacted significant effect with SF (Table 1 and Fig. 2). BLD percentage and BTA showed no significant change between feedback conditions and peak torque significantly decreased with SF by a mean decrease of 7.1 Nm compared to VF. This is unsurprising, however, as it is generally observed that in eccentric contractions higher velocities typically lead to greater force production [38]. However, in the case of a controlled NHE action, where a slower, constant descent speed and a neutral hip position are maintained, the torque–velocity relationship changes. Specifically, with reduced velocity, less force is produced, resulting in a left-ward shift in both the torque–length and torque–velocity relationships [39, 40]. The periods of acceleration that we observe during the NHE is due to task failure with acceleration due to gravity. Moreover, the SF was intentionally confined to modify NHE hip flexion and speed exclusively, and not injury risk factor metrics. Interestingly the upper ranges dropped significantly (Table 1 and Fig. 3) with SF for both RTA (57.9° to 34.6°) and AVK (61.6 $deg{\cdot}s^{-1}$ to 26.7 $deg{\cdot}s^{-1}$), which suggests that individuals initially exhibiting poorer exercise technique showed the most improvement, bringing them closer to the normal ranges.

The literature shows the impact of different hamstring exercises on muscle architecture and morphology and the implications this can have for injury prevention [41–43]. Notably, Baumgart et al. [42] reported that parametric and angle-specific flexion and extension torques differ according to hip flexion, velocity, and muscle contraction mode. Hamstring muscles operate differently across different lengths in response to changing exercise stimuli [43] and studies have suggested that injury is associated with a left-ward shift of peak torque to shorter angle lengths in the hamstrings [44]. The evaluation of the torque–angle relationship may be a useful tool for predicting hamstring strain injuries and as a return-to-play measure [45] and therefore standardized, controlled technique of exercises that measure torque–angular data are important, as a deviation of form can alter the intended nature of the exercise, impacting the desired adaptations, whether for training, angle-specific testing, performance optimisation, injury prevention or rehabilitation. Specifically, in the NHE, maintaining a neutral 0° hip position minimises variability in torque production, allowing for a more consistent and targeted training effect in the knee flexor muscles, however, whether this enhances the overall training effect depends on the specific adaptation being targeted, and further research is required [46, 47]. For NHE training interventions and testing, maintaining controlled technique (hip flexion and descent speed) is needed to understand the mechanisms driving observed adaptations to better inform practitioners. Software feedback can assist

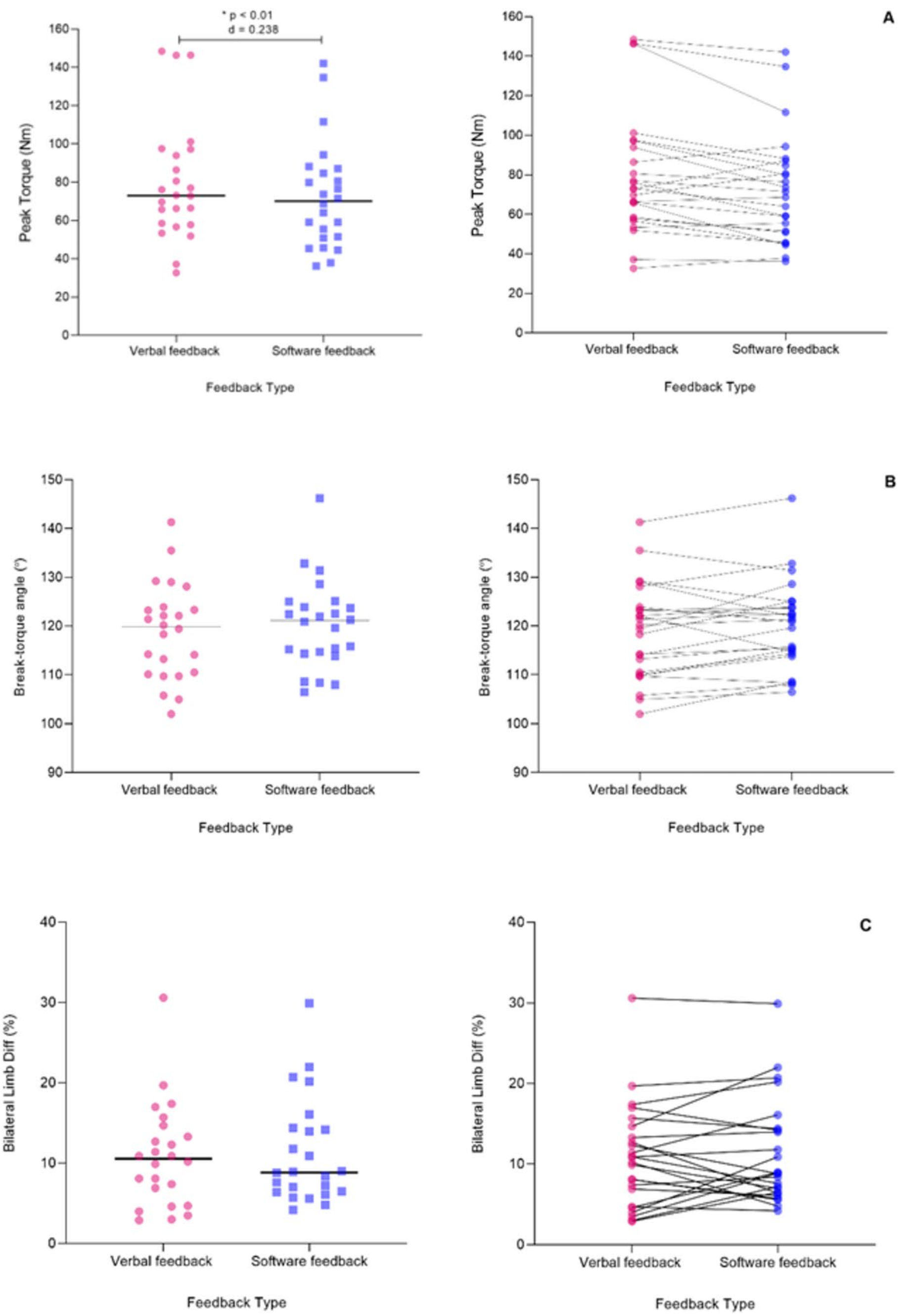

Fig. 2 Eccentric knee flexor peak torque (**A**), break torque angle (**B**), and bilateral limb difference (**C**) performance metrics for verbal feedback ($n=24$) and software feedback ($n=24$) conditions. Asterisks (*) indicate any significant differences between feedback conditions

in ensuring proper form throughout the exercise, therefore supporting more reliable and consistent outcomes.

Chalker et al. [21] reported an increase in mean peak force production when using feedback, however it was specific to force–time traces on a screen and not hip and knee angles, or movement velocity. Moreover, if increased torque is a result of suboptimal exercise technique, there is a risk of overestimation which has implications in hamstring training intervention studies where precise quantification of change is important for assessing the effectiveness of the intervention [48]. Additionally, the production of peak torque within a shorter muscle length range is less useful for targeting the site of hamstring injuries [10, 44]. It is, therefore, reasonable to hypothesise that integrating SF into chronic NHE training, using a moving reference line on-screen and supplementing it with the option to visualise torque-time traces and break-point failures as part of a performance/injury-risk software mode would be beneficial.

Several advantages of the biofeedback system include immediate user correction, engagement, and better exercise technique. The system reinforces proper NHE form by visually guiding users through the correct range of motion

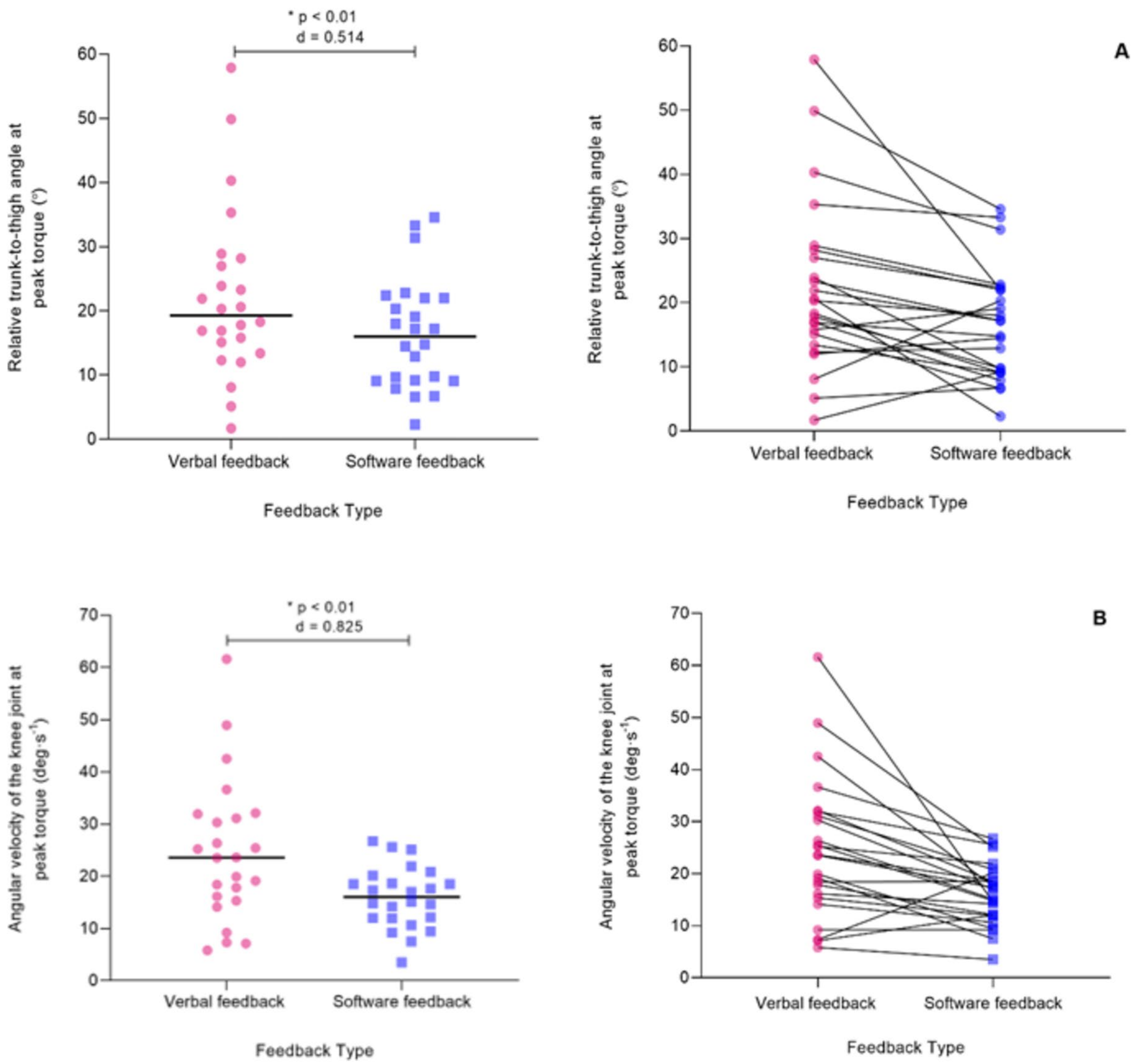

Fig. 3 Angular velocity of the knee joint (**A**) and relative trunk-to-thigh angle (**B**) at peak torque technique metrics for verbal feedback ($n=24$) and software feedback ($n=24$) conditions. Asterisks (*) indicate any significant differences between feedback conditions

and pace. Real-time feedback helps avoid overextension or rapid movements that could lead to strain. As users receive immediate visual cues, they can make adjustments allowing them to course-correct during the exercise. The visual representation and reference line create an interface experience, encouraging users to maintain focus and adherence, which is a major issue in NHE compliance [49]. It is suggested that acute feedback is most beneficial when of high frequency (during every rep), and of a visual kinematic nature [27] which the HA*L*HAM° SF system offers.

The limitations of the study are relatively modest sample numbers and the absence of a separate pre-testing familiarisation phase as noted in Alt and Schmidt [5]. Nonetheless, our focus examined changes in metrics with SF rather than preparing athletes for exhaustive performance testing or training. User feedback recommended that the reference line start from a position behind neutral, featuring an initial slightly flexed knee position with a 'preliminary movement phase' to allow the user to adjust to the pace before passing through the neutral position. As a result, the test is then initiated in a manner that ensures a controlled and smoother commencement. Another consideration for SF adjustment would be defining an anatomically aligned hip flexion angle reflecting natural physiological curvature of the lumbar spine, within a permissible range of up to 20° as suggested by, Alt and Schmidt [5]. This modification would expand the cautionary orange range to encompass values up to this threshold and subsequently set the red range beyond it. Alt and Schmidt [5] recommend NHEs should be executed with a constant knee extension velocity of 15 deg·s^{-1} across the

NHE range of motion, with a 10 deg·s^{-1} deviation of this being classed as the break-point (failure). Again, setting a cautionary range for AVK of between 15 and 25 deg·s^{-1} should be explored in future work.

Implementing a flexible SF system for NHE training where the individual could customise the AVK and RTA threshold, would be advisable. This would support the required muscle adaptations required for personalised hamstring training. For instance, faster eccentric loading velocity could be advantageous for recruiting higher hamstring muscle activation [50], whereas a slower velocity with controlled hip flexion might be preferable for optimising TUT, without using the accessory muscles to maximise the preferential protective adaptations of hypertrophy and longer BFlh fascicle length required for HSI prevention. Ongoing user familiarisation of the feedback system over the long term would be required to evaluate its effectiveness for this type of purpose.

Conclusion

The HA*L*HAM° integrated SF system significantly improves acute NHE technique (RTA and AVK), benefitting individuals initially exhibiting poorer technique the most. A customizable SF system with a performance mode option may be beneficial for NHE chronic intervention training and testing to elicit desired protective muscular adaptations and lower hamstring strain injury risk.

Author contributions ES, BH, TMW and NH were responsible for the conception of the study. NH and BH were responsible for the design and implementation of the device hardware and software. ES was involved in the data collection and conducted the analyses. ES drafted the manuscript, which was critically revised by the coauthors. All authors reviewed and approved the final manuscript.

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Data availability The data that support the findings of this study are available from the corresponding author, [ES], upon reasonable request. The Universities secure research ennvironment is: https://shurda.shu.ac.uk/

Declarations

Conflict of interest The authors declare no competing interests.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent to publish Participants signed informed consent regarding publishing their data.

Ethics approval The study was performed in line with the principles of the Declaration of Helsinki. Ethical approval for the study was approved by the Sheffield Hallam University Ethics Committee (Date: 24/03/2021/No ER29609708).

Informed consent Informed consent was obtained from all individual participants included in the study.

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