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Development of a Novel Biofeedback System for the Sprint Start

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Abstract

This study developed and evaluated a novel concurrent biofeedback system for the sprint start. Previous studies have investigated sprint start biofeedback applications, but these have either not considered important kinematics, coaching implications or key motor learning principles. The biofeedback system was developed to convey rear knee angle information, obtained from 3D motion capture to novice participants as changes in the colour of an LED start line when they were in the “set” position. Based on initial user feedback, the system indicated whether the participants’ rear knee angles were within ±2° of 130° (green) or not (red). A two-group experimental study was then employed to explore the acute responses of novices to the use of the biofeedback system during the sprint start. When exposed to biofeedback, the experimental group (EXP, n = 10) exhibited less deviation (4.0 ± 2.4°) from the target rear knee angle than they did in either a pre-test (11.9 ± 6.9°) or post-test (10.4 ± 4.4°) condition without biofeedback. The control group (CON, n = 10) with no biofeedback exhibited greater deviation from the target rear knee angle than the EXP group in all three condition blocks (pre-test = 21.8 ± 15.1°, no intervention = 15.6 ± 7.3°, post-test = 14.3 ± 6.5°) but the group × condition interaction effect was not significant (P=0.210). The novel biofeedback system can be used to manipulate selected “set” position kinematics and has the potential to be incorporated with different input systems (e.g. IMUs) or in longitudinal designs.

Keywords: Biomechanics, Sport, Motor Control, Sprint Start

Word Count: 4594

Introduction

The objective of all sprint events is to translate the whole-body centre of gravity (CoG) over a given distance (60 to 400 m) in the shortest amount of time, and the importance of the start is well established[1,2,3,4]. A powerful start allows athletes to achieve greater velocities earlier in the race[5,6], and this 'all-out' strategy is associated with improved overall sprint performance[7].

In all sprinting events that abide by World Athletics regulations, athletes must follow "on your marks" and "set" commands prior to the official start of the race which is marked by the starter's gun[8]. The position of athletes when in the stationary "set" position is likely an important component of an effective start[9,10]. An appropriate "set" position may enable increased power generation because of greater impulse production in a shorter period of time[7,9]. Therefore, it is essential for athletes to learn and be able to attain the "set" position adequately and reliably during training and competition, and this is typically facilitated by technical coaching, often through the provision of feedback.

The sprint start is an asymmetric gross motor skill requiring rapid actions and it has therefore been classified as a complex motor skill[11,12]. Athletes are broadly recommended to position their hips above their shoulders and their shoulders ahead of their hands, which, respectively, translate the whole-body CoG higher and bring it horizontally closer to the start line[13]. Knee joint kinematics in the "set" position have been relatively widely investigated, and the rear knee angle has been identified as an important feature[2,13,14,15]. The rear knee has been found to be more extended in elite (136 ± 11°) than in well-trained (117 ± 10°) sprinters[13], and this may assist with the higher and more anterior placement of the whole-body CoG[2,13,16,17]. The rear leg contributes ~30% of the total horizontal block impulse despite its relatively short pushing duration[18,19] and rear leg force magnitudes are important predictors of block phase performance[20,21]. Although the ideal rear knee angle may differ between individuals due to a range of factors, and there is therefore unlikely to be a universally optimal "set" position rear knee angle, the rear knee kinematics in the "set" position are likely important for enabling a sprinter to achieve their desired whole-body CoG positioning and may assist the production of favourable rear leg forces during its relatively short push against the block.

While the biomechanics of the sprint start have been widely investigated and features such as the importance of the rear knee action have been established, most studies have been descriptive and cross-sectional. Only a few studies have attempted technique-related interventions for the sprint start, but these have been limited by a lack of supporting motor learning considerations and/or the technology used to present relevant information to the participants[22,23,24]. For a biofeedback protocol to be effective, it must be tailored to the characteristics of the movement skill and the athletes, and be based on relevant motor learning considerations such as the cognitive load of biofeedback[25], biofeedback modality[26,27] (auditory, visual or haptic), timing[28], frequency[28,29], focus of attention[30] and knowledge of results/performance[31]. A concurrent visual biofeedback system therefore offers a potentially viable solution when integrated within the training environment for complex motor skills such as the sprint start[33,34]. Coaches may then be able to implement such tools into training to supplement more traditional feedback methods. During complex motor skills, simple, integrated visual displays can be effective due to their low ambiguity[26,35,30,28], in particular for novice athletes performing complex movement skills to aid them in learning the general movement patterns[27,36]. For example, Eriksson et al. (2011) implemented a concurrent simple visual display to successfully modify running mechanics on a treadmill, similar to Luc-Harkey et al. (2018) during walking, whilst Shea and Wulf (1999) found that using concurrent visual displays resulted in improved learning of a balancing task, and Wulf, Shea and Matschiner (1998) found similar results during a dynamic ski simulation task. A simple visual display which has the potential to be integrated into a complex applied environment for whole-body tasks would therefore provide a novel and potentially effective method of providing biofeedback regarding "set" position kinematics, especially for novice sprinters learning the block start. The aim of the present study was therefore to develop and evaluate a simple light-based visual biofeedback system for assisting the near real-time adoption of specified lower limb kinematics in the "set" position of a sprint start.

Methods

Biofeedback System Development:

The biofeedback system was developed using a strip of LEDs (Lightstrip Plus base V4, Koninklijke Philips N.V., Amsterdam, Netherlands) which was integrated with input information from a motion capture system so that it changed colour based on participants' rear knee angles in near real-time. The chosen biofeedback light configuration was based on a pilot study which investigated three different light-based configurations during broad jumps as a general analogue without exposing inexperienced participants to sprint start trials prior to the main study. The pilot study and main study were approved by the Research Ethics Committee of the lead author's host institution (approval number 2018-063), and all participants provided written informed consent. Participants of the pilot study (two males, nine females; Mean ± SD; age: 21.3 ± 1.7 years; mass: 60.6 ± 7.9 kg; height: 167.6 ± 7.3 cm) undertook a series of broad jumps under each of three biofeedback configurations: a binary configuration (green when knee angle was within ± 4° of the target knee angle (90°) and red when not) and two graded configurations (same as binary but with the addition of amber when knee angles were within ±5° or ±10° of the green target range, respectively). The 4° threshold was selected during development of the biofeedback system as a range that was sufficiently challenging to achieve but which did not lead to frequent small deviations outside of the target range when attempting to maintain a target angle for some participants, as occurred with lower thresholds. The binary configuration led to a higher success rate (64%) in adoption of the prescribed knee angle when compared to both graded configurations (40% and 39%, respectively). Participants also received a questionnaire following each condition and 55% of participants preferred the binary configuration to both graded configurations (18% and 27%, respectively).

During the biofeedback protocol for the sprint start, the LEDs were positioned directly on top of the start line and were therefore in line of sight of participants during the “set” position (Figure 1). Based on the above pilot study, a binary biofeedback system was adopted which was configured to show green when the rear knee angle of participants was between 128° and 132° and to show red when outside of this range. Participants’ rear knee angles were recorded in real-time at 250 Hz using a 12-camera motion capture system (T-20, Vicon, Oxford, UK) which recorded synchronously with force-instrumented starting blocks (Pace Insights Ltd., Leamington Spa, UK) at 1000 Hz. A custom seven-segment (pelvis, two feet, two shanks, two thighs) rigid-body lower-body model was used, which included anatomical markers on joints and landmarks, and additional three-marker clusters on the shank and thigh segments. Anatomical markers were placed on the posterior calcanei, the medial and lateral aspects of the first and fifth metatarsal heads, respectively, superiorly on the second metatarsal head, on the medial and lateral malleoli, the medial and lateral aspects of the knee joint flexion-extension axis, and on the anterior superior iliac spines, superior lateral aspects of the iliac crest and posterior superior iliac spines. Three-marker clusters were placed on the lateral aspect of each thigh and shank segment at ~30% of the segment length in an asymmetric manner to aid real-time marker labelling and reconstruction. The anatomical markers were used to define participant-specific models during a static trial and to track the pelvis and feet during the sprint start trials, whilst the marker clusters were used to track the shank and thigh segments during the sprint start trials. The rear knee flexion-extension angle was reconstructed from the shank and thigh segments in near real-time using a six degrees-of-freedom reconstruction by streaming the marker data to Visual3D (Visual3D V5, C-Motion, Germantown, MD, USA). A biofeedback script was implemented in Visual3D whereby a pop-up window changed between red and green based on the current rear knee angle. ScreenBloom software (v 2.2) was then used to relay information from the coloured pop-up window to the LEDs via a Philips Hue Bridge (Philips Hue Home Automation Smart Bridge 2.0, Koninklijke Philips N.V., Amsterdam, Netherlands). A ~0.2 s delay in the real-time provision of the biofeedback information was determined using a high-speed video camera (PXW-Z150, Sony, Tokyo, Japan) and was deemed sufficiently low for participants to appropriately respond to in pilot trials during the development of the biofeedback system.

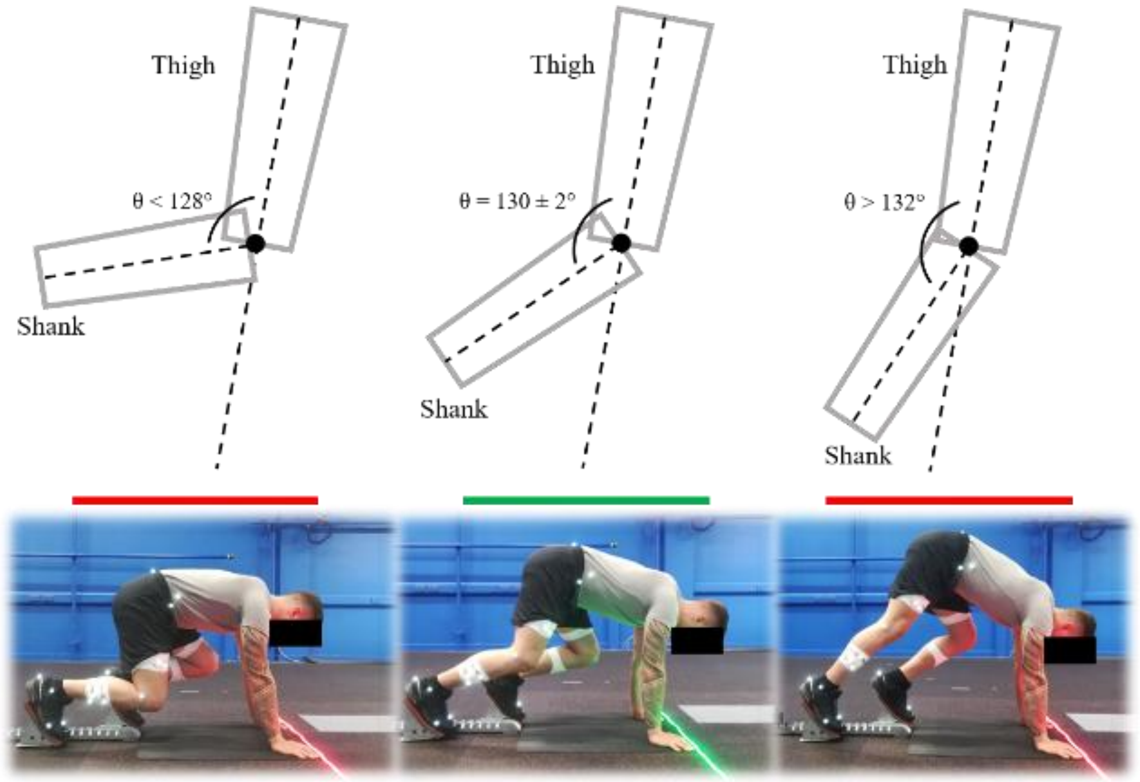

Figure 1 – Illustration of the LED activation ranges while in the "set" position during the intervention condition for a novice sprinter in the EXP group. A rear knee angle of 130 ± 2° causes the LEDs to be green, and all other angles cause the LEDs to be red.

Experimental Design:

To evaluate the effectiveness of the novel biofeedback system, a simple pre-post experimental design was used to investigate the acute effect of a biofeedback intervention using this system on “set” position technique during a single laboratory visit. Twenty healthy and currently injury-free participants (10 males, 10 females; mean ± SD; age: 21.8 ± 2.1; mass: 67.7 ± 10.8 kg; height: 169.9 ± 10.7 cm) who exercised regularly but had never undergone any sprint start training and had not used starting blocks prior to this study performed five sprint start trials under each of three conditions (pre-test, intervention (or control) and post-test). The participants were assigned in a counterbalanced manner into either the experimental (EXP; four males, six females) group, which received biofeedback during the intervention condition, or the control (CON; six males, four females) group, which did not receive any biofeedback during any of their conditions.

Upon arrival at the laboratory, participants’ leg dominance was determined by asking them to lean forward until loss of balance. The leg that was brought forward to stop the fall was considered “dominant” and was placed in the rear block. Block placement was prescribed for all participants based on their directly measured leg length, with inter-block spacing set to 45% of leg length and the front block-start line distance set to 50% of leg length[10]. Due to their lack of familiarisation with the task, the sprint start protocol was verbally explained to all participants as per World Athletics guidelines (including “on your marks”, “set” commands, and a clear audible start signal). All participants were given general information about “set” position technique (i.e. hands immediately behind start line and hips higher than shoulders) and were shown a visual spatial model of an athlete in such a position in the blocks, in which the rear knee was clearly identified at 130°. All participants were asked to attempt to attain a rear knee angle of 130° during the “set” position. As highlighted previously, it is likely that the ’optimal’ rear knee angle in the “set” position may differ between individuals, but a consistent value was used for all participants given the primary aim of this study being the development of a proof-of-concept system that could subsequently be tailored for individuals. For the present study, 130° was selected as it is attainable by novice sprinters[14] and broadly appropriate based on the kinematics of experienced and elite sprinters[13,15,16].

After a self-directed warmup, participants performed five familiarisation trials, which were not included in the analysis. During the familiarisation trials, if participants did not follow one of the general starting instructions (hands immediately behind start line, hips higher than shoulders), the most relevant cue was repeated, but no further 'technical' feedback was given. Each trial consisted of a 5 m maximal effort sprint commencing from starting blocks. A two-minute rest was allowed between all trials and during this time participants were verbally reminded of the 130° rear knee angle objective and to produce maximum effort sprint starts. If requested, participants were also able to view the spatial model again. Following familiarisation, all participants in both groups performed five sprint starts under the pre-test condition with no biofeedback. After the pre-test condition, participants in the EXP group were then introduced to the biofeedback system, including how to interpret it and the ~0.2 s delay. During the subsequent intervention/control condition, the EXP group were given concurrent visual biofeedback using the biofeedback system, whilst the CON group performed a further five sprint starts without biofeedback, but they were reminded of the intended 130° rear knee angle. Following the intervention/control condition, biofeedback was removed from the EXP group and both groups were again reminded of the 130° rear knee angle target and to produce maximal effort sprints. Five sprint starts followed under the post-test condition with no biofeedback present for either group.

Data Analysis:

The raw resultant force data from the instrumented starting blocks was used to identify movement onset and block exit. Movement onset was identified as the first instance where resultant force deviated (for more than 10 frames) by more than 3 standard deviations from the mean force during a clear visually identified stationary position prior to this. Block exit was defined as the first instance after movement onset when resultant force was less than 50 N. The "set" position was defined as the 0.6 s prior to movement onset, and the mean rear knee angle over this duration was determined. The root mean squared difference of this mean rear knee angle from 130° (θ_{RMS}) was also determined for each trial. Average horizontal external power was calculated as $mv^2/2t$ and used as the main performance measure[37], where m = body mass, v = block exit velocity which was determined from the antero-posterior pelvis CoG displacement during the first flight phase after block exit[37], and t = block time which was defined as the duration from movement onset to block exit. These values were then normalised[37] to provide normalised average horizontal external power (hereafter simply termed block power).

Group (CON, EXP), condition (pre-test, intervention or control, post-test) and interaction (group × condition) effects were calculated for θ_{RMS} and block power using a mixed ANOVA ($\alpha = 0.05$) on SPSS software (SPSS v.25, IBM) following recommendations by Field (2000)[38]. Effect sizes for group, condition and interaction were calculated using Cohen's f test. Pairwise comparisons were performed using a Bonferroni post-hoc test, and pairwise effect sizes were calculated using Cohen's d[38,39]. Cohen's f thresholds were categorised as small (f: $0.10 \leq f < 0.24$), medium ($0.25 \leq f < 0.40$) and large ($f \leq 0.40$) while Cohen's d thresholds ranged from trivial ($d < 0.20$), small ($0.20 \leq d < 0.60$), medium ($0.60 \leq d < 0.12$), large ($0.12 \leq d < 2.00$) and very large ($2.00 \leq d < 4.00$).

Results

Rear knee angles during the "set" position for the CON group showed gradual changes between the first (mean ± SD; pre-test: 112.9 ± 20.2°), second (intervention/control: 120.7 ± 14.6°) and third (post-test: 128.3 ± 15.8°) conditions (Figure 2). These changes occurred as a gradual decrease in mean rear knee angle difference to the 130° target as well as in decreasing standard deviations across the group. The EXP group changed from the first (pre-test: 121.5 ± 12.7°) to second (intervention/control: 127.1 ± 3.5°) condition both in terms of average rear knee angle relative to target as well as in lower standard deviation across the group. During the third condition (post-test: 129.0 ± 11.3°) the EXP mean rear knee angle continued to increase towards the 130° target, while the group standard deviation regressed to near pre-test value.

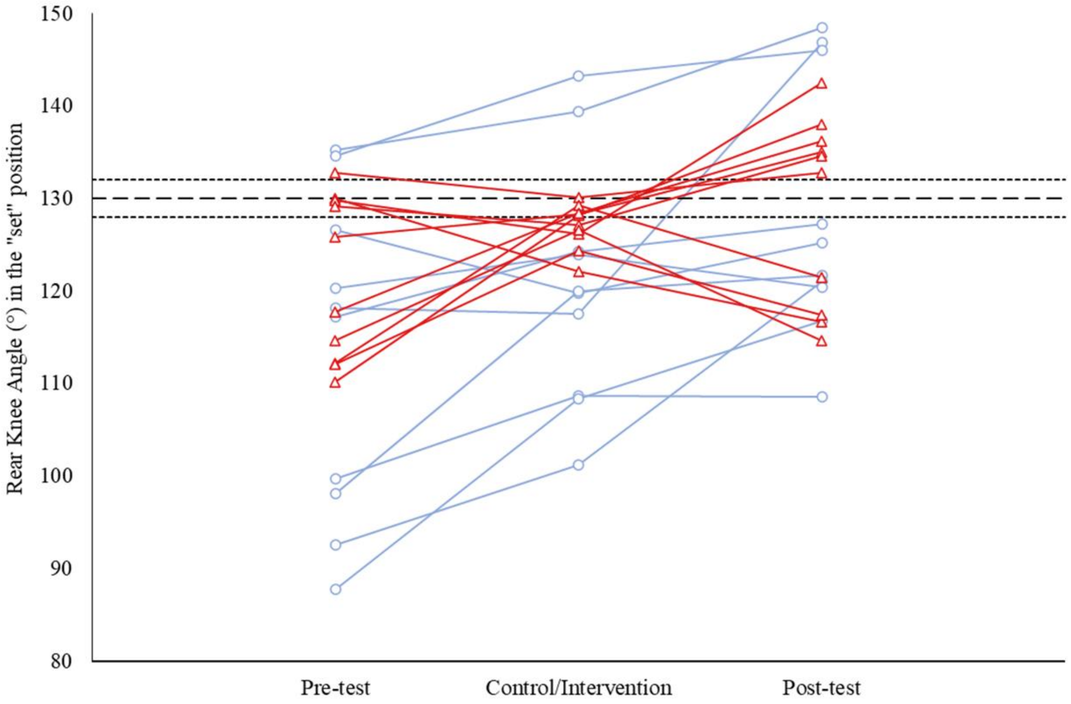

Figure 2 – Mean rear knee angles of all participants in the CON (blue) and EXP (red) groups in each condition. The horizontal lines show the 130° rear knee angle target ± the 2° green activation ranges for the LEDs.

Group mean and 95% confidence intervals values for θ_{RMS} in each condition are shown in Figure 3. There was a significant (p = .023) effect of condition on θ_{RMS} with large effect sizes (f = 0.54). Pairwise comparisons between conditions revealed that θ_{RMS} during the middle intervention/control condition was significantly (p = .019) less than at pre-test with a very large effect size (d = 3.08). Post-test was not significantly different from pre-test (p = .224) or intervention/control (p = .367), although large effect sizes (d = 1.89 and 1.62, respectively) were observed. Between-subject effects showed that the CON group displayed a significantly

(p = .004) greater θ_{RMS} than the EXP group with large (f = 0.78) effect sizes. The interaction effect of condition and group was not significant (p = .210) with moderate effect sizes (f = 0.30).

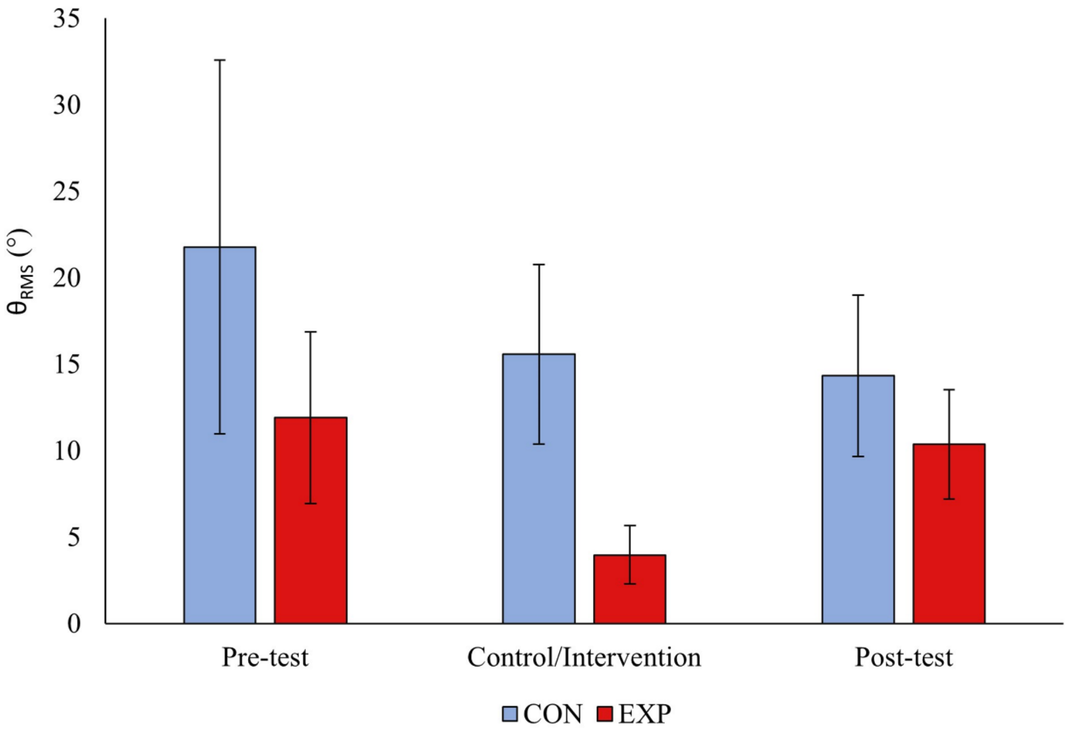

Figure 3 – Root mean squared rear knee angle (θ_{RMS}*) during "set" position for CON and EXP groups in each condition. Error bars show the 95% confidence intervals.*

Group mean and 95% confidence intervals values for Block power in each condition are shown in Figure 4. There was a significant (p = .002) effect of condition on block power (large effect size: f = 0.78). Pairwise comparisons showed block power at pre-test and post-test were significantly (p = .015 and p = .042, respectively) greater than in the intervention/control condition (very large effect sizes; pre-test: d = 3.38; post-test: d = 3.00). Pre-test was not significantly different (p = .416) to post-test (large effect size: d = 1.55). There was no significant (p = .511) effect of group (CON, EXP) on block power (small effect size: f = 0.20), and no significant (p = .336) interaction effect (moderate effect size: f = 0.30).

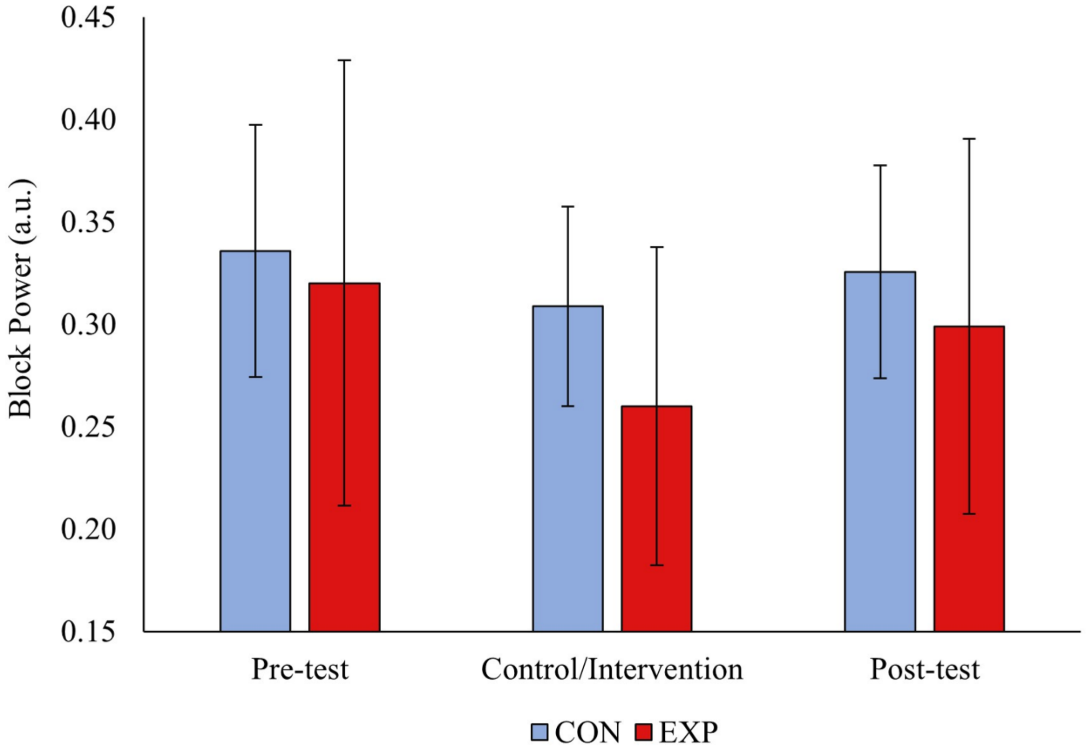

Figure 4 – Mean block power for CON and EXP groups in each condition. Error bars show the 95% confidence intervals.

Discussion

This study developed a light-based visual biofeedback system for the sprint start, and successfully used this system in an acute intervention with an experimental group of 10 of the 20 studied novice sprinters. The biofeedback system was programmed to provide this EXP group with a clear signal when their rear knee angle was in the intended configuration (130°) in the “set” position. Based on the results of the mixed ANOVA for the root mean squared difference of this measured rear knee angle from 130° (i.e. θ_{RMS}), there was a significant between-subject effect of group and a significant within-subject effect of condition on θ_{RMS}, but there was no significant interaction effect of group and condition. This may, in part, be due to the 10° between-group mean difference in θ_{RMS} at baseline (pre-test; Figure 3), which occurred by chance as the groups were allocated in a counterbalanced order, as well by the considerable between participant variation (within and between both groups) as could be expected when studying novice participants being asked to perform a complex motor skill with minimal prior instruction.

Without any use of the biofeedback system or any additional extrinsic feedback, the CON group exhibited a gradual decrease in θ_{RMS} across the three conditions (i.e. the mean knee angle of this group became closer to 130°), but there remained considerable between-participant variability throughout all conditions (Figures 2 and 3). This trend in the CON group corresponds to the theoretical learning effect of blocked practice with no feedback provided, showing constant improvements in technique for participants learning a new skill[34]. In contrast, The EXP group, who had the benefit of the novel biofeedback system during the middle condition, did not exhibit such a linear pattern (Figures 2 and 3). The EXP group showed a mean decrease of 7.9° in θ_{RMS} from pre-test (11.9 ± 6.9°) to the intervention condition (4.0 ± 2.4°), in which the SD across the group was also lowest of any condition, and then a 6.4° mean increase to near pre-test levels during the post-test condition (10.4 ± 4.4°). These findings provide support for the effectiveness of the developed biofeedback system in acutely enabling participants to modify their rear knee angle during the "set" position in order to exhibit values closer to the desired target, and to obtain values which were closer to the target than a group with no feedback (CON), even after three blocks of five trials.

The fact that the EXP group regressed to near their pre-test θ_{RMS} values in the post-test condition, despite the clear reduction in θ_{RMS} during the intervention condition, indicates that there was no retention of motor learning from biofeedback. This was not surprising given the current study design as this is an expected outcome from practice over a single session[31]. Motor learning requires longer-term practice to elicit neurological changes, in turn causing changes in movement patterns[31], and the purpose of the current study was to evaluate the acute effectiveness of the novel biofeedback system. Future studies employing similar light-based biofeedback systems may seek to extend the current study by incorporating established principles which have been shown to be effective in changing an athlete's well-established technique, for example using the Five-A Model[32] and prescribing training over multiple weeks[22,32,40] in order to assess the potential retention effects associated with such a feedback modality.

As this study was primarily focused on the development and efficacy of the biofeedback system for enabling participants to acutely control certain joint configurations, performance effects were only a secondary consideration. Whilst there was no significant effect of group or interaction effect on block phase performance (i.e. block power), there was a significant effect of condition (Figure 4). Block power was lowest in the middle control/intervention condition, with the mean reduction being greatest in the EXP group (Figure 4). It is possible that the use of the biofeedback acutely influenced performance levels as the participants' focus was diverted towards the biofeedback goal rather than the task itself[34,29]. A reduction in the frequency at which biofeedback is presented may also be beneficial with such a system, and may allow participants to better explore their technique between conditions (i.e. with and without biofeedback) during practice[25, 29]. This may be especially relevant during longer-term studies as concurrent visual biofeedback may interfere and degrade motor learning during practice when used in high frequency[29]. In the present study the EXP group experienced high feedback frequency during the middle control/intervention condition because the study aim was to determine the acute effectiveness of the system and not the long-term changes. Investigators and coaches aiming to modify the technique of athletes using such real-time biofeedback systems should consider the different feedback frequencies and practice sequence that might best allow athletes to explore possible changes in their technique. Future research could also explore this further, particularly as a consideration in the aforementioned longer-term studies where participants may progressively become more familiar with the biofeedback within the same task and environment.

The present biofeedback system was developed based on motor learning considerations and was informed by qualitative and quantitative evidence from a preliminary pilot study. The system was developed with the primary aim of conveying complex continuous kinematic information (rear knee flexion-extension angles) as simple visual signals that could be incorporated into the training environment of the sprint start. During the development of the biofeedback system, a binary configuration was selected above two possible graded configurations. The pilot study participants' perceptions obtained through questionnaires revealed that the binary configuration was simpler to understand and therefore preferable. This may be explained by the lower cognitive load of simpler biofeedback configurations, shown to be beneficial during complex movement tasks for novice performers[34,41], particularly as the amber colour could represent a knee angle that was slightly too extended or slightly too flexed. Additionally, the questionnaire responses indicated that the choice of colours (green and red, plus amber in the graded configurations) displayed by LEDs were intuitive to interpret by participants. Rear knee angles were selected as the kinematic variable of choice for biofeedback due to their established importance in the sprint start[2,13,14,15]. However, numerous aspects of the developed biofeedback system are easily modifiable and could be adapted to specific features of "set" position technique that a coach may consider desirable as well as the specific joint angle ranges prescribed for these. This flexibility also allows researchers or coaches in other sports to adopt a similar approach and implement their own kinematic prescriptions to other movement tasks with similar characteristics and demands to the sprint start.

The current inputs to the biofeedback system are highly accurate due to coming from a 12-camera motion capture system and a full three-dimensional reconstruction based on marker clusters. As this was a first development of a biofeedback system based on smart LEDs, motion capture system inputs were used to provide a high level of internal validity in the kinematic variable of interest (i.e. rear knee angles) being fed back to the participants. However, this means that the current system is constrained to laboratory-based activities due to its reliance on these inputs. The integration of such a biofeedback system with other inputs from technologies such as inertial measurement units (IMUs) provides a future opportunity for a lower cost and more ecologically valid alternative for extending this towards a more field-based biofeedback system. Furthermore, the current iteration of the biofeedback system yielded a delay of approximately 0.2 s between participants' movements and the visual feedback they received. Whilst this was appropriate for the current self-paced and relatively slow movement of adopting a "set" position, pilot trials with single markers have demonstrated that the lag between participant movement and biofeedback can be considerably reduced by bypassing the Visual3D and Screenbloom software used in the current system. While concurrent biofeedback delays in are typically not reported in published studies, longer delays may result in increased difficulty when interpreting biofeedback. Concurrent biofeedback systems should ideally be able to provide an output within a small portion (10-20%) of the human reaction time of that given task and for the target population[42,43]. Future developments should therefore explore improvements towards more field-based inputs and/or reduced delays, which could render systems based on similar principles more viable for feedback during dynamic movements, but they should remain cognisant of the accuracy of the raw and/or reconstructed data when making such changes.

In the present study, the biofeedback prescription encouraged participants to attain a 130° rear knee angle. This was chosen as a consistent exemplar position for all participants as there is unlikely to be a single 'optimal' "set" position for all individuals[1,13]. It is likely that what constitutes a more beneficial "set" position is specific to individuals due to differences in strength and anthropometrics[13] and it will also be influenced by the kinematics at other joints including the neighbouring ankle and hip[15]. A biofeedback system based on the developments described in the current study has the potential to be used in a field setting to guide individual athletes towards a “set” position that is beneficial to them based on their own individual constraints and the experiential knowledge of the coach. In addition to the aforementioned future work to improve the technology towards more field-based inputs and reduced delays, researchers should also seek to apply such systems to longer-term training studies to ascertain the potential for more permanent changes in technique in response to a simple light-based biofeedback protocol based on the principles which have been developed in the current study.

The present study developed a novel light-based biofeedback system that was successfully integrated into a laboratory environment. The system was used to provide near real-time biofeedback which, when present, enabled participants to improve their adoption of prescribed rear knee joint angles during the “set” position of a sprint start. Further research and application is required to explore the longitudinal effects of such a system on the learning of novel movements, and different inputs, which could reduce delays or enable use in more ecologically valid and simulated competition environments, are also encouraged. Future iterations of light-based biofeedback systems may enable coaches to precisely and concurrently guide an athlete’s movements during training. Coaches and researchers aiming to implement such light-based biofeedback with athletes should consider motor learning principles (such as focus of attention, feedback frequency and cognitive load) alongside working models (such as the Five-A Model[32]) in an attempt to use such biofeedback systems to effectively and permanently refine technique over longer intervention timescales[25,29,32]. Further research should also investigate the effect of similar biofeedback systems on different movements as well as with trained participants who have prior experience of the movement being manipulated.

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Declaration of interest: None

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