Effect of different anthropometry-driven block settings on sprint start performance

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Abstract

Few studies have focused on the effect of individual anthropometrics when considering "set" position posture during the sprint start. This study aimed to measure the effect of different anthropometry-driven block settings on kinetic and kinematic parameters and performance during the start in well-trained and non-trained sprinters. Front block-starting line (FB/SL) distance was manipulated between 50% and 70% of each individual's leg length at 5% intervals, whilst the inter-block distance was held constant at 45% of leg length. Thirty-six sprinters performed three maximal-effort 10 m sprints in each of the five conditions. Joint angles in the "set" position were quantified though 2D video analysis, the forces generated during block clearance phase were measured by dynamometric starting blocks, and times to 5 m and 10 m were measured with photocells. The effects of the five block setting conditions were largely consistent irrespective of ability level. Shorter FB/SL distances were associated with significantly more flexed hip and knee angles in the "set" position, a significantly more plantar flexed front ankle, and a significantly more dorsiflexed rear ankle. There were no significant effects of FB/SL distance on total block time, and thus the greater rear block peak forces and impulses produced from the shorter FB/SL distances combined with no effects on the resultant front block peak forces and impulses, led to higher levels of sprint start performance from the shorter FB/SL distances. Considering FB/SL distances closer to 50% of leg length may be beneficial for coaches and athletes to explore during sprint start training.

Highlights

- The effects of different front-block starting line distances on "set" position kinematics, block clearance kinetics and sprint start performance are largely consistent irrespective of ability level.

- When using a medium inter-block distance (45% of leg length), shorter front block-starting line distances (down to 50% of the leg length) led to improved sprint start performance.
- From shorter front block-starting line distances, sprint start performance was primarily improved through greater force production against the rear block which led to greater impulses due to no change in push durations or resultant front foot forces.
- Lower-limb length is an important consideration when adjusting anteroposterior block distances.

Key words: sprint running, set position, biomechanics, anthropometrics.

Introduction

The start is a crucial skill for a sprinter to maximize overall sprint performance (Baumann, 1976; Mero, 1988; Slawinski et al., 2010; Bezodis et al., 2015; Willwacher et al., 2016; Bezodis et al., 2019b). An effective sprint start is influenced by the way sprinters position themselves in the blocks at the "set" command (Slawinski et al., 2012) and the mechanics of leaving the blocks after they react to the gun (Bezodis et al., 2015; Otsuka et al., 2015; Willwacher et al., 2016; Brazil et al., 2017; Bezodis et al., 2019a).

The regulations allow sprinters to adjust the anteroposterior block distances and the inclination of the block pedals. One of the most common adjustments is the inter-block (I-B) distance, which is classified into a bunched (< 30 cm), medium (30 to 50 cm) or elongated (> 50 cm) start (Henry, 1952; Stock, 1962; Harland and Steele, 1997). Several studies have suggested that a medium start is superior for sprint start performance by providing the most favorable balance between total force generated and the time spent generating force (Stock, 1962; Slawinski et al., 2012; 2013; Cavedon et al., 2019).

When the starting blocks are adjusted to a medium start based on an individual's leg length (I-B distance = 45% of leg length; Cavedon et al., 2019) compared with sprinters' usual block settings (mean I-B distance = 33.8% of leg length), block clearance kinetics and subsequent step characteristics are affected. Cavedon et al. (2019) also manipulated the front block-starting line (FB/SL) distance (to 60% of leg length, compared with 63.9% as the mean usual setting for the studied group) and found that changes in this distance were predictive of changes in rear block external kinetics such as peak force and impulse. As the most predictive factors of sprint start performance are associated with the magnitude of force generated by the rear leg (Willwacher et al., 2016; Bezodis et al., 2019a), manipulation of the anteroposterior block distances, in particular the FB/SL distance, may affect sprint start performance, potentially through changes in rear hip extensor action (Cavedon et al., 2019).

Definitive block spacing recommendations currently remain challenging, particularly for the FB/SL distance, because of the variation in the spacings used and the dependent variables adopted between studies. Although numerous studies have focused on the influence of anteroposterior block distance modifications on kinetic and kinematic parameters, little consideration has been given to the potential interaction with an individual's body dimensions (Dickinson, 1934; Henry, 1952). Lower-limb length was recently found to be predictive of a sprinter's usual FB/SL distance irrespective of sex and ability level, suggesting that this anthropometric dimension provides a suitable parameter for determining an initial FB/SL distance when exploring "set" position technique (Cavedon et al., 2022). Relationships between the FB/SL distance and "set" position front hip angle were also found, and these hip kinematics were consequently associated with numerous kinetic variables during the block clearance phase, highlighting the importance of lower-limb length when adjusting FB/SL distance (Cavedon et al., 2022).

At present, the effects of block settings driven by an individual's leg length on starting block performance remain poorly understood. Although there appears to be no universal optimum body posture in the "set" position, and it is likely that the same "set" position will not lead to the same performance effects between individuals, the current available evidence suggests that anthropometry-specific anteroposterior block distances which facilitate hip extension and a greater rear leg contribution should be investigated. Thus, a detailed investigation of body postures in the "set" position is required to further the understanding of the interactions between an individual's body dimensions, their block settings, and the consequent biomechanical parameters exhibited during the block clearance phase. This could assist coaches and athletes in their pursuit of ideal personal block spacings to potentially increase sprint start performance.

The aim of this study was therefore to investigate the effect of five different anteroposterior block distance settings on biomechanical parameters in well-trained and non-trained sprinters, in an attempt to identify anthropometry-driven block settings which may be beneficial for block clearance phase performance. The block setting conditions were selected based on previous studies (Schot and Knutzen, 1992; Cavedon et al., 2022) to manipulate FB/SL distance based on an individual's leg length. Based on the findings of Cavedon et al. (2019), an FB/SL distance of 60% of leg length was used as the reference condition, and four further conditions (50%, 55%, 65%, 70%) were investigated. As a medium I-B distance has repeatedly been shown to be more effective than bunched or elongated distances (Stock, 1962; Schot and Knutzen, 1992; Slawinski et al., 2012), an I-B distance of 45% of leg length was held constant across the five conditions. We hypothesized that sprint start performance would be improved from block settings with a smaller FB/SL distance than the 60% of leg length reference condition.

Methods

Participants

Thirty-six participants (15 well-trained sprinters and 21 non-trained sprinters) gave their written informed consent to participate in the study. The well-trained sprinters (3 women and 12 men) had a competitive sprinting career of at least two years and their age, height and body mass (±SD) were 18.60 ± 3.56 y, 173.35 ± 6.63 cm and 65.03 ± 10.48 kg, respectively. All well-trained sprinters were involved in regional and national level competitions and trained at least 5/6 times a week for 2/3 hours per day. Their best time over 100 m ranged between 11.50 s and 13.14 s for women and between 10.50 s and 12.02 s for men. Non-trained sprinters' (5 women and 16 men) age, height and body mass (±SD) were 22.52 ± 3.40 y, 174.05 ± 8.43 cm, and 67.75 ± 11.47 kg, respectively. All the non-trained sprinters were university exercise and sport sciences students who participated in sports such as soccer, baseball, cycling, and had only experienced block starts in four practice lessons on their degree course. They did not have a personal best time in an official 100 m race. The protocol was performed in accordance with the Declaration of Helsinki. Ethical approval was obtained from the University Institutional Review Board (Prot. N. 290/2012).

Procedure

The sprint testing took place on an outdoor track (Olimpic Plast SWD surface, Olimpia Costruzioni, Forlì, Italy). One operator attached ten retro-reflective passive flat markers (14 mm diameter) bilaterally over specific anatomical landmarks on each participant's body (acromion, greater trochanter, lateral epicondyle, lateral malleolus, on the shoe lateral to the 5th metatarsal head).

Following a warm-up consisting of jogging, dynamic stretching and sprints of submaximal intensity, all participants performed 15 maximal-effort 10 m sprints from the five different block setting conditions: the front block/starting line distance was set according to individual leg length (Schot and Knutzen, 1992; Cavedon et al., 2019) at 50%, 55%, 60%, 65% and 70%, and the inter-block spacing was fixed at 45% of leg length for all conditions (Fig. 1). Each trial was performed using a set of dynamometric starting blocks equipped with load cells (see *Kinetic and kinematic data* section).

The order of conditions was randomized for each participant. Block obliquity was set to each individual's preference and held constant across all conditions. All participants wore running shoes so that comparisons could be made across the two groups under the same conditions. Each sprint was initiated by the same experimenter who provided standard 'on your marks' and 'set' commands. The experimenter then pressed a custom-designed trigger button to provide the auditory start signal through a sounder device. The rest period between trials was 5-7 minutes.

Anthropometric data

Anthropometric data were taken by one operator using conventional criteria and measuring procedures (Lohman et al., 1992). Body mass was assessed to the nearest 0.1 kg using a certified electronic scale (Tanita electronic scale BWB-800 MA, Wunder SA.BI. Srl, Milano, Italy). Standing height was measured to the nearest 0.1 cm using a Harpenden portable stadiometer (Holtain Ltd., Crymych, UK). Lower-limb length was measured to the nearest 0.1 cm with a Harpenden anthropometer (Holtain Ltd., Crymych, UK) as the distance between the greater trochanter and the lateral malleolus.

Kinetic and kinematic data

External forces were collected using force instrumented starting blocks (CU K5D and CU K1C, GEFRAN SpA, Brescia, Italy) enabling the measurement of the magnitude and direction of external forces generated during the block clearance phase at 1 kHz (sensitivity was 0.01 N). The x-axis was horizontal and pointed forward along the direction of the running lane, and the y-axis pointed vertically upwards for each block. More detailed information concerning the starting blocks can be found in Cavedon et al. (2019).

Two tripod-mounted video cameras (Casio Exilim ex-zr 1000, Casio Europe Gmbh, Barcelona, Spain) captured the movement of each athlete in two dimensions during the block clearance phase and the first and second steps at 200 Hz. The cameras collected images at a resolution of 1280 × 1024 pixels using a shutter speed of 1/1000 s, and were 5 m from the outside lane at a height of approximately 1 m. One camera (Camera 1) was positioned for the front block side view and another (Camera 2) for the rear block side view; both were perpendicular to the running lane in line with the approximate location of the respective hip joint in the "on your marks" position.

Photocells (Polifemo Light Radio, Microgate SRL, Bolzano, Italy) were used to measure the times to 5 m and 10 m. The starting blocks and photocells were synchronized by connecting a digital output from the block control system to an input for timing on the photocells, and this also provided the input to the auditory start signal.

Data analysis

The raw data from the instrumented blocks were filtered using a low-pass Butterworth filter (fourth order) with a cutoff frequency of 120 Hz and analyzed using a custom program in Matlab R2008a (MathWorks, Natick, MA, USA). The force onset threshold was identified when the first derivative of the resultant force-time curve was greater than 500 Ns^{-1}, and block clearance when the resultant force was lower than 50 N. The following measures were then extracted: reaction time (RT), front block time (FBT), rear block time (RBT), total block time (TBT), front peak force and its components (FPF; H_FPF and V_FPF), rear peak force and its components (RPF; H_RPF and V_RPF), average total force (ATF), front force impulse and its components ($FF_{impulse}$; H_ $FF_{impulse}$ and V_ $FF_{impulse}$), rear force impulse and its components ($RF_{impulse}$; H_ $RF_{impulse}$ and V_ $RF_{impulse}$) and total force impulse (Total $F\_{impulse}$). More detail concerning the calculation of these can be found in Cavedon et al. (2022). All kinetic variables were normalized to body mass. In addition, the following performance parameters were computed: horizontal block velocity (H_BV) as the sum of the horizontal impulse on both blocks (Ns) divided by body mass (kg); normalized average horizontal external power (NAHEP) calculated according to the procedures of Bezodis et al. (2010).

For each participant the video clips were digitized at full resolution with a zoom factor of 2.5 using Kinovea (version 0.8.15, http://www.kinovea.org). One operator manually digitized the markers and quantified the hip, knee and ankle flexion/extension joint angles (full extension = 180°) at specific frames on each video. The videos from Camera 1 were used to determine the front leg joint angles and the videos from Camera 2 were used to determine the rear leg joint angles, all of which were measured to the nearest degree.

In order to limit the potential effects of operator error, one experienced operator repeated the above procedures in three separate sessions, with a minimum of seven days between sessions. The mean value was recorded only when the coefficient of variation was <5%. As the markers can move in relation to the skin throughout the range of motion (Reinschmidt et al., 1997) despite being properly positioned prior to data collection, the operator paid close attention to this and visually adjusted for any skin movement by only using the markers as a guide in line with the procedures of Bradshaw et al. (2007).

Statistical analysis

As the present study used a repeated-measures design with five conditions, these measures are likely to be more similar to each other than measurements between different participants. Mixed-effects models were therefore used to provide an approach which accounted for this within-subject correlation and allowed a wide variety of correlation patterns to be explicitly modeled (Brown and Prescott, 1999). For each outcome, the mixed-effects model contains one random effect on the intercept (subjects), and four fixed variables: one categorical variable (block setting condition) and three potential confounders (age, sex, ability level). The parameters were estimated using the restricted maximum likelihood, due to its unbiasedness properties in balanced-data problems, applying the modification proposed by Kenward and Roger (1997) to account for limited sample size. In order to investigate the presence of a linear trend in the mean biomechanical parameter under the five block setting conditions, the F statistic for testing a linear contrast was used (Maxwell et al., 2018), with $\alpha = .05$ implying the existence of a statistically significant linear relationship between the average value of the outcome and the block setting positions. The significance of any differences between the reference block setting position (60%) and each of the four block setting positions was tested through the significance ($\alpha = .05$) of the parameters of the categorical variable for the four conditions, and evaluated using the Wald test. Statistical analyses were performed using Stata 16.1 (StataCorp. College Station, TX, USA).

Results

There was a significant difference (P < 0.001) in mean age between the well-trained and non-trained groups, but there were no significant differences between the two groups for any other demographic, anthropometric or block distance variables (Table 1).

Set position lower limb joint angles.

In the whole sample and in both subgroups by ability, the mean values of both hip and both knee joint angles for the five block setting conditions showed a statistically significant positive linear trend for an increased angle (i.e., more extended) as the five FB/SL distances increased (all P < 0.001; Table 2; Fig. 1). A significant positive linear trend (i.e., more plantar flexed at increased FB/SL distances) was also found for the rear ankle joint angle (whole sample: P < 0.001; non-trained: P = 0.028; well-trained: P = 0.011; Table 2; Fig. 1). A significant negative linear trend (i.e., more dorsiflexed at increased FB/SL distances) was observed for the front ankle joint angle for increasing values of the FB/SL distance (all P < 0.001; Table 2; Fig. 1).

Temporal block parameters.

In the whole sample and the well-trained sprinters, the mean values of the RT showed a statistically significant positive linear trend for increasing values of the FB/SL distance (P = 0.008 and P = 0.027, respectively; Table 3). In the whole sample and in both subgroups, the mean values of the FBT showed a statistically significant negative linear trend for increasing values of the FB/SL distance (P < 0.001 for the whole sample and well-trained sprinters; P = 0.008 for the non-trained sprinters; Table 3). A similar response was observed for the RBT in the whole sample (P = 0.005) and in the non-trained sprinters (P = 0.010; Table 3). No significant differences were found for TBT in the whole sample or the subgroups (Table 3).

Kinetic and kinematic parameters during the block clearance phase.

In the whole sample, the mean values of the RPF and $RF_{impulse}$ (including when separated into both components) showed a statistically significant negative linear trend for increasing values of the FB/SL distance (all P < 0.001 [Figure 2] aside from V_RPF from the non-trained subgroup where P = 0.002; Table 3). There was no significant effect of FB/SL distance on FPF or $FF_{impulse}$ (or the vertical components of these), but there was a significant positive trend for H_FPF in the whole sample (P = 0.007) and in the well-trained subgroup (P = 0.035) and for $H\_FF_{impulse}$ in the whole sample (P < 0.001), non-trained (P = 0.011) and well-trained (P < 0.001) subgroups (Table 3). When the kinetics were summed across both blocks, the mean values of ATF and Total $F_{impulse}$ also showed a statistically significant negative linear trend for increasing values of the FB/SL distance (all P<0.001; Table 3).

Starting block performance parameters.

In the whole sample and in the subgroups by ability, the mean values of the H_BV and NAHEP showed a statistically significant negative linear trend for increasing values of the FB/SL distance (all P < 0.001; Figure 2 and Table 3). The mean values of the times at 5 and 10 m both showed a positive linear trend for increasing values of the FB/SL distance (all P < 0.001; Table 3).

Discussion

We investigated the effects of different anteroposterior block distances, which were based on a proportion of individuals' leg lengths, on block clearance phase parameters in well-trained and non-trained sprinters in an attempt to identify anthropometry-driven block settings which may be beneficial for block phase performance. Our results indicated that: 1) the effects of the five block setting conditions were largely consistent across both ability level groups, 2) the progressive FB/SL distance modifications led to consistent "set" position joint angle changes in both legs, despite the I-B distance remaining fixed, 3) the shorter FB/SL distances yielded higher rear block peak forces and impulses, and the total block forces and impulse were also highest from the shorter FB/SL distances because the front block resultant peak force and impulse were unaffected by the FB/SL distance changes, and 4) the shorter FB/SL distance was better for all performance measures, confirming our hypothesis.

The primary effect of the manipulation of the FB/SL distance was to induce postural adaptations in the "set" position resulting in significantly more extended angles of all joints in both legs as the FB/SL distance increased, except for the front ankle joint angle, which was significantly more dorsiflexed. It has been shown that a lower "set" position (i.e., the centre of mass closer to the ground) with greater flexion at both hips, the front knee and the rear ankle is beneficial for generating greater H_BV and NAHEP (Slawinski et al., 2010; Čoh et al., 2017; Cavedon et al., 2019). Moreover, it has been demonstrated that both hip joint angles were negatively correlated with rear block force and impulse generation (i.e., more extended angles were associated with lower forces; Cavedon et al., 2022). It is therefore likely that the more flexed hips and knees in the "set" position in the shorter FB/SL distance conditions in the current study were associated with the improvement in several kinetic variables during the block clearance phase (Table 3), and also with the improvements in sprint start performance. The front hip and knee joints have been found to be more flexed in the "set" position in faster than slower sprinters (Mero et al., 1983; Bezodis et al., 2015; Ciacci et al., 2017), a positive relationship has been found between rear hip extension during the block clearance phase and NAHEP (Bezodis et al., 2015), and hip extensor kinetics are a key contributor to block phase performance (Otsuka et al., 2015; Brazil et al., 2017). The current study has added new experimental information to the understanding of the importance of the hip actions by identifying that a closer FB/SL distance affects the configuration of hips in the "set" position, which leads to enhanced NAHEP, likely through higher hip power generation based on the above evidence from previous studies. Of note is that whilst these previous findings relate to trained sprinters, in our study the changes across the five conditions were similar between well-trained and non-trained sprinters. This suggests that the "set" position of a sprinter in the blocks does not need to be an important distinguishing factor between sprinters of different ability levels *per se*. In addition to shorter FB/SL distances being beneficial for trained sprinters who likely have greater technical proficiency and explosive strength, shorter FB/SL distances could also be beneficial for sprinters from the very outset as they first learn the block start.

Despite the I-B distance being fixed at 45% of leg length across all conditions, the rear leg hip and knee joint angles also experienced a significant effect of FB/SL distance and were smallest in the 50% FB/SL distance condition. This suggests that the FB/SL distance can be used to manipulate rear leg kinematics and that any changes made to either the FB/SL distance or the I-B distance should likely consider the anteroposterior block settings as a whole. The decrease in rear hip joint angle as the FB/SL distance decreased was expected, whereas the decrease for the rear knee joint angle was not. This may be explained by either a shorter distance between the rear foot and the starting line or a shorter distance between the CM and the start line with the shoulders further ahead in the "set" position. It is also possible that a greater proportion of the body mass could be supported through the legs rather than the arms. This could increase the pre-tension in the hip (or knee) extensors and/or the stretch-reflex in the ankle plantar flexors, either of which could be beneficial for performance if increases in the kinetic output from these joints result from such changes (Brazil et al., 2017; 2018; Mero et al., 2006). However, further research is required to explore this suggestion and better understand the interactions between anteroposterior block distances, "set" position angles and block clearance actions, including the possible interactions between the FB/SL and the I-B distances in combination.

The rear knee joint angles in the 50% FB/SL distance condition were of similar magnitude to those previously reported (Milanese et al., 2014). Our findings, combined with those of Milanese et al. (2014), provide experimental within-sprinter evidence that a more flexed rear knee angle in the "set" position was associated with higher block velocities than more extended angles. This confirms the important role played by the rear knee joint during the block clearance phase (Charalambous et al., 2012; Milanese et al., 2014) and also extends it beyond well-trained sprinters to non-trained sprinters, suggesting that it is a general mechanical feature and not something which is a function of sprint training and adaptation. The more flexed rear leg joint angles, especially at the knee, in the shorter FB/SL distance conditions likely contribute to the significantly improved RPF and $RF_{impulse}$, and their horizontal components, which ultimately contribute to the increased performance levels. This is supported by previous evidence which shows that the FB/SL distance is an important predictor of rear block force production (Cavedon et al., 2019) and the established link between rear block force magnitude and NAHEP (Willwacher et al., 2016; Bezodis et al., 2019a). The current results therefore add further evidence to this understanding, extending the knowledge of the role of the rear leg action and identifying the potential link to the rear leg joint angles in the "set" position.

There was no significant effect of condition on TBT, but there was an effect on both FBT and RBT, with both being longer from the shorter FB/SL distances. As the start of RBT coincides with the start of TBT and the end of FBT coincides with the end of TBT (see Figure 1 in Cavedon et al., 2019), this suggests that the shorter FB/SL distances lead to a longer push against both blocks without there being a concomitant increase in the duration of the total push against the blocks (i.e. the front block push started earlier and the rear block push finished later), a factor which likely contributed to the greater performance (H_BV and NAHEP) from these shorter FB/SL distances. When considering performance and the durations of phases within the blocks, it is also important to note that the 5 m and 10 m times include the RT component so these performance measures might be influenced by the longer RTs observed from the 70% condition for the whole sample. Given the many complexities associated with RT and its measurement (Milloz et al., 2021), further direct investigation of the effect of FB/SL on RT is warranted, but the observed effects on NAHEP confirm the potential performance advantage associated with the shorter FB/SL distances as this does not consider RT.

In the whole sample, TBT was similar across the five block setting conditions, and a similar response was observed within each of the subgroups (although the well-trained sprinters exhibited shorter TBTs than the non-trained sprinters). The similar TBT values across the five block setting conditions within each of the sub-groups confirm that the greater H_BV with the shorter FB/SL distances (Figure 2) was due to increased force production, not an increase in the duration of the push against the blocks, a fact also supported by the NAHEP results. This greater Total $F_{impulse}$ at the shorter FB/SL distances was due to an increase in the $RF_{impulse}$ because the $FF_{impulse}$ and FPF did not change across the five conditions (Table 3). Based on our results, this was likely due to a greater RPF but may also have been due to consistently higher forces throughout the push phase; either way our findings confirm the importance of enhancing force production against the rear block (Willwacher et al., 2016; Bezodis et al., 2019a). Interestingly, although the FB/SL distance did not affect $FF_{impulse}$, there was a significant increase in the $H\_FF_{impulse}$ component as the FB/SL distance increased. Whilst the longer FB/SL distances led to a greater horizontal component of the $FF_{impulse}$, it was not beneficial for overall performance because of the greater concurrent reduction in the $H\_RF_{impulse}$. Such a negative interaction between front and rear block force production has previously been identified by Brazil et al. (2018) who proposed that it could be due to either neuromuscular factors or different "set" position configurations, and our results confirm that changes to a sprinter's "set" position could influence this interaction. Further direct exploration is therefore warranted, including manipulating FB-SL distance in combination with varying I-B distances, to understand how this influences the contributions across both blocks and ultimately to identify ideal individual settings which may maximize the total horizontal impulse produced across both blocks.

The study has certain limitations that should be acknowledged. 2D kinematic measurement was used which may have led to parallax error in the kinematic measurements given that the sprint start is not a perfectly planar movement. However, as all kinematic variables were reported from the "set" position, this error would likely be small and the current data provide valuable new biomechanical evidence to further understand the effects of different anteroposterior block distances on sprint start technique and performance. Secondly, as we prioritised identical conditions across all studied participants, the well-trained sprinters were not wearing spiked shoes and this must be considered in the application of the current findings. Finally, our results were obtained at a single instant in the training year for the well-trained group, and it is possible that changes in physical capacity across the season may influence the technical and performance outcomes from given block settings, and future research may wish to investigate this where possible.

In conclusion, these findings confirm the important role of lower-limb length when adjusting FB/SL distance, irrespective of a sprinter's experience. When using a medium I-B distance (45% of leg length), shorter relative FB/SL distances (down to 50% of leg length) led to greater rear block forces and impulses and ultimately to higher levels of sprint start performance in both well-trained and non-trained sprinters. Considering anthropometry-driven block settings based leg length may therefore help coaches and athletes when searching for a more effective starting technique.

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Conflict of interest

The authors declare no conflicts of interest.

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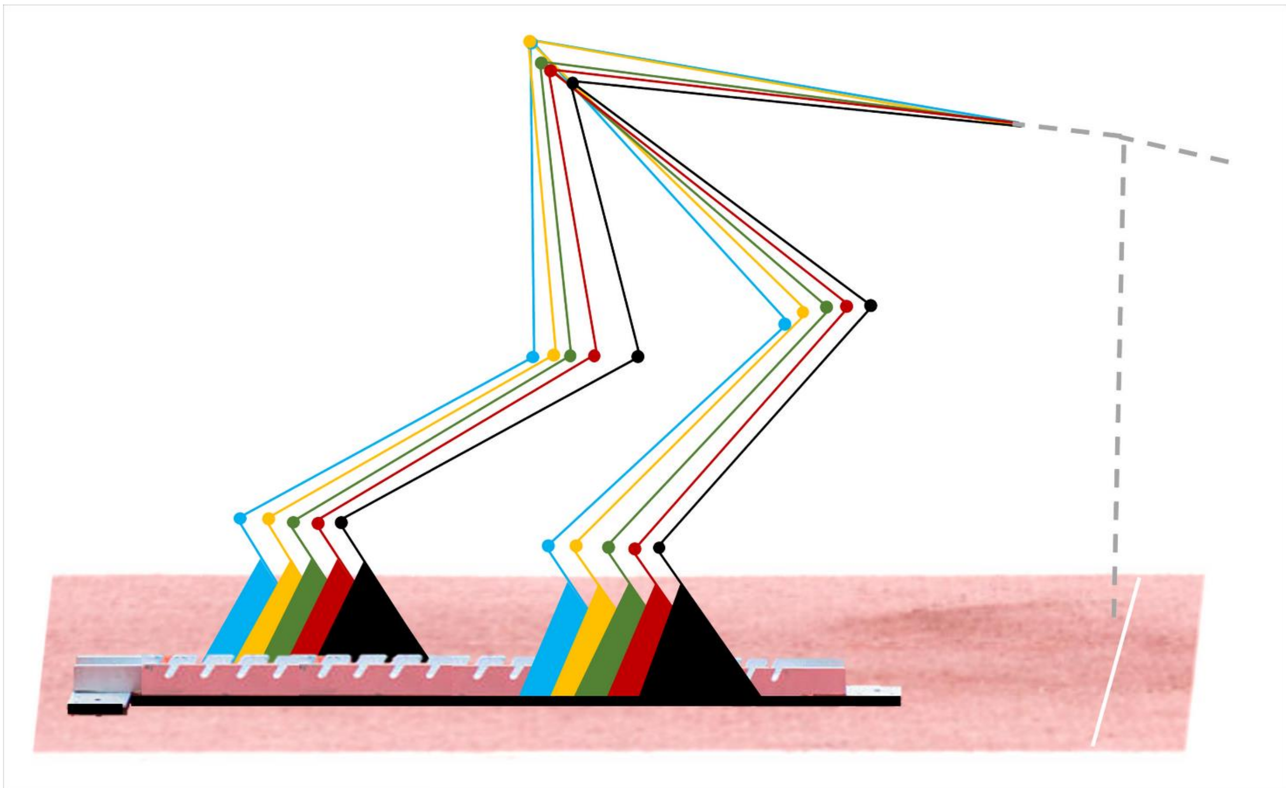

Figure 1. A visual representation of the mean body configurations adopted by the whole sample from each of the different front block-starting line distances based on a proportion of individual leg length: 50% (black), 55% (red), 60% (green), 65% (yellow), 70% (blue). Note: the inter-block distance was held constant at 45% of leg length for all conditions.

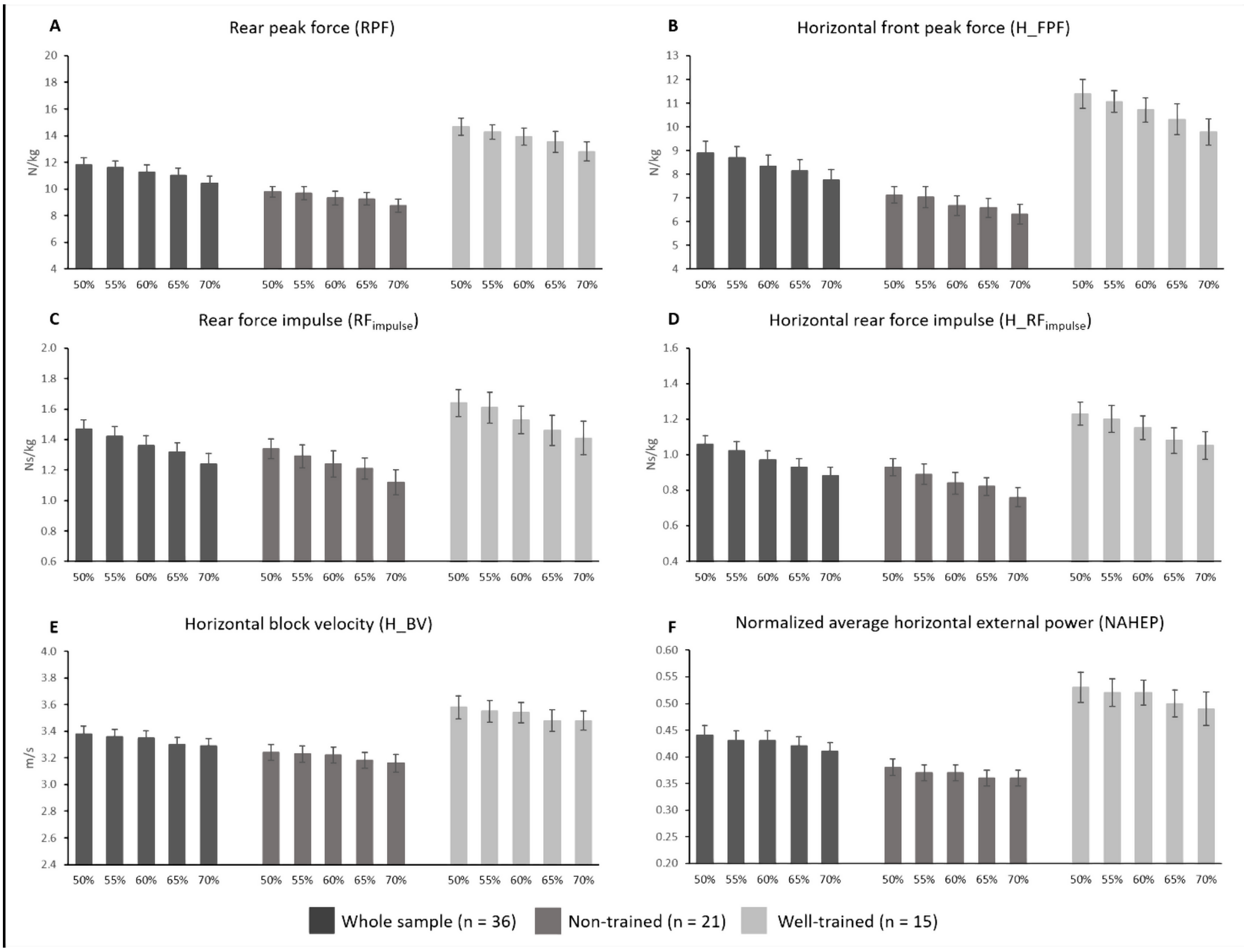

Figure 2. Selected biomechanical parameters under the five block setting conditions in the whole sample and both subgroups. Data are mean ± standard error. All main effects for the whole sample and each sub-group were statistically significant (P < 0.001), please see Table 3.

Table 1. Characteristics of the participants in the whole sample and also when divided between the two ability level groups, and the anteroposterior block distances of the five block setting conditions. Data are means ± SD.

Variable	Whole sample (n=36)	Non-trained (n=21)	Well-trained (n=15)
Age (y)	20.89 ± 3.94	22.52 ± 3. 40	18.60 ± 3.56***
Body mass (kg)	66.61 ± 11.00	67.75 ± 11.47	65.03 ± 10.48
Height (cm)	173.76 ±7.63	174.05 ± 8.43	173.50 ± 6.63
Lower limb length (cm)	83.87 ± 5.41	84.22 ± 5.51	83.39 ± 5.41
FB/SL distance 50% (cm)	41.94 ± 2.70	42.11 ± 2.76	41.69 ± 2.71
FB/SL distance 55% (cm)	46.13 ± 2.97	46.32 ± 3.03	45.86 ± 2.98
FB/SL distance 60% (cm)	50.32 ± 3.24	50.53 ± 3.31	50.03 ± 3.25
FB/SL distance 65% (cm)	54.52 ± 3.51	54.74 ± 3.58	54.20 ± 3.52
FB/SL distance 70% (cm)	58.71 ± 3.78	58.95 ± 3.86	58.37 ± 3.79
I-B distance 45% (cm)	37.74 ± 2.43	37.90 ± 2.48	37.52 ± 2.43

FB/SL: front block-starting line; I-B: inter-block; *** significantly ($P < 0.001$) different from the non-trained group.

Table 2. Mean values (SD) of set position joint angles for the five block setting conditions for the whole sample and also when stratified between the two ability-level groups; P columns report the significance of the test for trend on the means; the superscript asterisks for the mean values at the 50%, 55%, 65%, 70% conditions indicate the significance of the difference compared to the 60% reference condition (* P<0.05; ** P<0.01; *** P<0.001).

Variable	Whole-sample (n=36)						Non-trained (n=21)						Well-trained (n=15)					
	50%	55%	60%	65%	70%	P	50%	55%	60%	65%	70%	P	50%	55%	60%	65%	70%	P
Front Hip	33.16***	35.82***	37.81	39.45**	41.93***	***	31.25***	34.22*	36.15	36.44	39.56***	***	35.84***	38.04**	40.13	43.67***	45.24***	***
(°)	(7.16)	(7.91)	(7.79)	(8.59)	(9.79)		(6.29)	(7.43)	(7.19)	(7.80)	(8.62)		(7.64)	(8.20)	(8.23)	(8.05)	(10.66)	
Rear hip	72.05***	74.70***	78.69	80.17	83.46***	***	69.25***	72.30**	75.59	77.16	80.74***	***	75.96***	78.07***	83.04	84.38	87.27***	***
(°)	(10.62)	(10.77)	(11.45)	(11.96)	(13.46)		(10.13)	(10.45)	(10.70)	(10.87)	(12.45)		(10.36)	(10.66)	(11.40)	(12.49)	(14.30)	
Front knee	87.32	87.27	88.48	89.97	91.46***	***	84.11	82.94	85.08	85.37	87.91*	***	91.82	93.33	93.24	96.42**	96.42**	***
(°)	(9.78)	(11.37)	(10.38)	(11.41)	(10.11)		(9.21)	(10.99)	(9.90)	(10.75)	(10.17)		(8.98)	(9.11)	(9.37)	(9.17)	(7.90)	
Rear knee	106.18***	107.78**	112.06	116.09**	120.87***	***	101.57**	102.78*	106.62	110.39*	117.22***	***	112.64***	114.78*	119.69	124.07*	125.98**	***
(°)	(13.83)	(14.34)	(14.75)	(16.62)	(15.32)		(13.73)	(13.11)	(12.50)	(15.09)	(12.76)		(11.49)	(13.37)	(14.62)	(15.76)	(17.49)	
Front ankle	106.13***	104.22**	102.18	102.54	100.54*	***	109.07***	106.40**	103.83	104.41	102.73	***	101.80*	101.80	99.87	99.91	97.47*	***
(°)	(10.03)	(9.78)	(8.39)	(9.22)	(9.08)		(8.80)	(8.30)	(7.80)	(9.15)	(8.36)		(10.48)	(11.21)	(8.90)	(8.97)	(9.44)	
Rear ankle	92.31	92.01	92.44	93.35	94.42*	***	91.83	91.29	91.75	92.09	93.63	*	93.00	93.02	93.40	95.11	95.51	*
(°)	(10.72)	(10.41)	(9.81)	(9.82)	(10.19)		(8.51)	(9.05)	(8.34)	(8.63)	(9.51)		(11.97)	(12.33)	(11.81)	(11.37)	(11.33)	

Table 3. Kinetic and kinematic data during block phase and starting block performance measures: mean values (SD) for the five block setting conditions, for the whole sample and also when stratified between the two ability-level groups; P columns report the significance of the test for trend on the means; the superscript asterisks for the mean values at the 50%, 55%, 65%, 70% conditions indicate the significance of the difference compared to the 60% reference condition (* P<0.05; ** P<0.01; *** P<0.001).

Variable	Whole sample (n=36)						Non-trained (n=21)						Well-trained (n=15)					
	50%	55%	60%	65%	70%	P	50%	55%	60%	65%	70%	P	50%	55%	60%	65%	70%	P
RT	0.236	0.232	0.234	0.234	0.253**	**	0.243	0.241	0.238	0.237	0.262**		0.226	0.220	0.228	0.229	0.241	*
(s)	(0.06)	(0.05)	(0.04)	(0.05)	(0.06)		(0.05)	(0.05)	(0.04)	(0.05)	(0.06)		(0.06)	(0.05)	(0.05)	(0.05)	(0.05)	
FBT	0.428	0.427	0.423	0.421	0.416*	***	0.450	0.454	0.446	0.448	0.439	**	0.396	0.388	0.390	0.383	0.382	***
(s)	(0.04)	(0.05)	(0.04)	(0.04)	(0.04)		(0.03)	(0.04)	(0.03)	(0.03)	(0.03)		(0.03)	(0.02)	(0.02)	(0.02)	(0.03)	
RBT	0.241	0.235	0.235	0.235	0.230	**	0.247	0.242	0.243	0.244	0.232*	*	0.232	0.226	0.223	0.222	0.227	
(s)	(0.03)	(0.03)	(0.03)	(0.03)	(0.04)		(0.03)	(0.03)	(0.04)	(0.03)	(0.03)		(0.03)	(0.03)	(0.02)	(0.03)	(0.05)	
TBT	0.462	0.461	0.462	0.463	0.462		0.486	0.490	0.492	0.494	0.487		0.428	0.420	0.419	0.420	0.428	
(s)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)		(0.03)	(0.03)	(0.03)	(0.03)	(0.03)		(0.04)	(0.03)	(0.02)	(0.03)	(0.04)	
FPF	15.10	15.06	15.20	15.15	15.11		14.00	14.05	14.15	14.01	13.91		16.64	16.47	16.68	16.75	16.79	
(N/kg)	(2.35)	(2.31)	(2.30)	(2.40)	(2.52)		(1.98)	(1.95)	(1.86)	(2.06)	(2.09)		(1.95)	(2.07)	(2.06)	(1.93)	(2.12)	
RPF	11.82*	11.60	11.25	11.03	10.45***	***	9.78	9.69	9.34	9.25	8.76*	***	14.68*	14.27	13.92	13.52	12.81**	***
(N/kg)	(3.19)	(3.18)	(3.32)	(3.31)	(3.17)		(1.76)	(2.33)	(2.37)	(2.14)	(2.28)		(2.46)	(2.10)	(2.53)	(3.08)	(2.72)	
H_FPF	9.86*	9.88	10.03	9.95	10.07	**	9.11	9.12	9.29	9.14	9.27		10.92	10.94	11.07	11.10	11.20	*
(N/kg)	(1.49)	(1.46)	(1.42)	(1.48)	(1.53)		(1.10)	(1.08)	(0.99)	(1.04)	(1.12)		(1.32)	(1.28)	(1.30)	(1.23)	(1.32)	
V_FPF	11.47	11.39	11.44	11.45	11.27		10.67	10.71	10.69	10.65	10.38		12.59	12.35	12.50	12.57	12.52	
(N/kg)	(2.05)	(1.98)	(2.03)	(2.12)	(2.22)		(1.82)	(1.81)	(1.80)	(1.95)	(1.93)		(1.85)	(1.85)	(1.92)	(1.88)	(2.03)	
H_RPF	8.90**	8.71*	8.35	8.14	7.76**	***	7.13*	7.03	6.67	6.58	6.32	***	11.39*	11.06	10.71	10.32	9.78**	***

(N/kg)	(2.87)	(2.76)	(2.81)	(2.80)	(2.62)		(1.62)	(2.01)	(1.94)	(1.82)	(1.88)		(2.36)	(1.78)	(2.03)	(2.48)	(2.14)	
V_RPF	7.83	7.72	7.56	7.46	7.01***	***	6.78	6.73	6.59	6.54	6.09*	**	9.29	9.10	8.92	8.76	8.29*	***
(N/kg)	(1.89)	(1.93)	(2.08)	(2.06)	(2.01)		(1.23)	(1.42)	(1.66)	(1.39)	(1.54)		(1.68)	(1.71)	(1.85)	(2.17)	(1.91)	
ATF	11.10*	10.95	10.91	10.80	10.62***	***	10.35*	10.18	10.10	10.02	9.82*	***	12.14	12.04	12.05	11.89	11.74**	***
(N/kg)	(1.42)	(1.42)	(1.43)	(1.44)	(1.44)		(1.07)	(1.02)	(1.05)	(1.08)	(1.09)		(1.18)	(1.17)	(1.08)	(1.16)	(1.09)	
FF$_{impulse}$	3.51	3.50	3.55	3.54	3.53		3.56	3.59	3.61	3.60	3.54		3.45	3.38*	3.47	3.46	3.51	
(Ns/kg)	(0.40)	(0.49)	(0.43)	(0.43)	(0.45)		(0.35)	(0.47)	(0.44)	(0.44)	(0.43)		(0.46)	(0.51)	(0.42)	(0.43)	(0.49)	
RF$_{impulse}$	1.47***	1.42*	1.36	1.32	1.24***	***	1.34*	1.29	1.24	1.21	1.12**	***	1.64**	1.61	1.53	1.46	1.41**	***
(Ns/kg)	(0.35)	(0.40)	(0.39)	(0.36)	(0.41)		(0.30)	(0.35)	(0.39)	(0.31)	(0.37)		(0.34)	(0.39)	(0.35)	(0.39)	(0.43)	
Total F$_{impulse}$	5.08*	5.00	4.99	4.95	4.86**	***	5.01	4.97	4.95	4.92	4.76**	***	5.17**	5.05	5.04	4.98	4.99	***
(Ns/kg)	(0.50)	(0.44)	(0.44)	(0.46)	(0.50)		(0.50)	(0.43)	(0.44)	(0.48)	(0.53)		(0.49)	(0.46)	(0.45)	(0.46)	(0.45)	
H_FF$_{impulse}$	2.33*	2.34	2.38	2.37	2.41	***	2.31*	2.33	2.37	2.35	2.40	*	2.35	2.34	2.39	2.40	2.43	***
(Ns/kg)	(0.25)	(0.25)	(0.24)	(0.25)	(0.28)		(0.21)	(0.22)	(0.22)	(0.21)	(0.25)		(0.29)	(0.30)	(0.28)	(0.30)	(0.33)	
V_FF$_{impulse}$	2.59	2.55	2.59	2.58	2.53		2.66	2.67	2.67	2.68	2.57		2.48	2.39	2.47	2.45	2.48	
(Ns/kg)	(0.38)	(0.47)	(0.43)	(0.42)	(0.41)		(0.35)	(0.48)	(0.45)	(0.45)	(0.41)		(0.42)	(0.43)	(0.39)	(0.35)	(0.42)	
H_RF$_{impulse}$	1.06***	1.02*	0.97	0.93	0.88***	***	0.93**	0.89	0.84	0.82	0.76**	***	1.23**	1.20	1.15	1.08*	1.05**	***
(Ns/kg)	(0.27)	(0.31)	(0.31)	(0.28)	(0.30)		(0.22)	(0.27)	(0.28)	(0.23)	(0.25)		(0.25)	(0.29)	(0.26)	(0.28)	(0.30)	
V_RF$_{impulse}$	0.96**	0.94	0.90	0.87	0.81***	***	0.91	0.86	0.86	0.84	0.76**	***	1.03*	1.00	0.95	0.92	0.89*	***
(Ns/kg)	(0.25)	(0.27)	(0.27)	(0.25)	(0.30)		(0.23)	(0.24)	(0.29)	(0.23)	(0.28)		(0.27)	(0.30)	(0.26)	(0.29)	(0.32)	
H_BV	3.38	3.36	3.35	3.30**	3.29**	***	3.24	3.23	3.22	3.18	3.16*	***	3.58	3.55	3.54	3.48*	3.48*	***
(m/s)	(0.34)	(0.33)	(0.32)	(0.32)	(0.33)		(0.27)	(0.28)	(0.27)	(0.27)	(0.30)		(0.33)	(0.31)	(0.30)	(0.31)	(0.28)	
NAHEP	0.44	0.43	0.43	0.42*	0.41**	***	0.38	0.37	0.37	0.36	0.36	***	0.53	0.52	0.52	0.50	0.49**	***
	(0.11)	(0.11)	(0.11)	(0.11)	(0.10)		(0.07)	(0.07)	(0.07)	(0.07)	(0.07)		(0.11)	(0.10)	(0.09)	(0.10)	(0.08)	

5 m	1.26	1.26	1.28	1.29	1.31^{**}	***	1.31	1.31	1.32	1.34	1.36^{**}	***	1.19	1.18^{**}	1.22	1.21	1.24	***
(s)	(0.13)	(0.13)	(0.12)	(0.14)	(0.15)		(0.13)	(0.12)	(0.11)	(0.14)	(0.15)		(0.09)	(0.10)	(0.09)	(0.10)	(0.12)	
10 m	2.03	2.02^{*}	2.05	2.05	2.08^{**}	***	2.10	2.11	2.12	2.13	2.15^{*}	***	1.93	1.91^{**}	1.95	1.94	1.98	***
(s)	(0.18)	(0.18)	(0.17)	(0.19)	(0.20)		(0.18)	(0.16)	(0.16)	(0.19)	(0.19)		(0.14)	(0.13)	(0.13)	(0.14)	(0.16)	

RT, reaction time; FBT, front block time; RBT, rear block time; TBT, total block time; FPF, front peak force; RPF, rear peak force; H_FPF, horizontal front peak force; V_FPF, vertical front peak force; H_RPF, horizontal rear peak force; V_RPF, vertical rear peak force; ATF, average total force; $FF_{impulse}$, front force impulse; $RF_{impulse}$, rear force impulse; Total $F_{impulse}$, total force impulse; $H\_FF_{impulse}$, horizontal front force impulse; $V\_FF_{impulse}$, vertical front force impulse; $H\_RF_{impulse}$, horizontal rear force impulse; $V\_RF_{impulse}$, vertical rear force impulse; H_BV, horizontal block velocity; NAHEP, normalized average horizontal external power; 5 m, time at 5 meters; 10 m, time at 10 meters.