CHANGES IN SPRINT START PERFORMANCE DUE TO VARIATION IN BLOCK PEDAL ANGLES ON NON-EXPERIENCED, BUT COACHED PARTICIPANTS

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Athletes have considerable freedom to set the starting blocks in athletics sprint events. We aimed to understand how the block pedal angle changes influence force production and performance of the start. Fifteen non-experienced, but coached participants performed a total of 18 starts each (three starts with each of six different block settings) in a random order. Linear mixed modelling of ground reaction forces (1000 Hz) and motion data (200 Hz) yielded 6.4% higher values ($p<0.05$) of average horizontal external power with block pedal angles of 40° in comparison to 60° angles. Varying the pedal angles induced joint angle changes at the set position, which in turn resulted in increased force production at the lower pedal angles. This was probably due to more favourable muscle-tendon unit lengths for force production at the lower block pedal angles.

KEY WORDS: forces, GRF, horizontal power, linear mixed model, sprinting

INTRODUCTION: Biomechanical research of the sprint start in athletics has experienced a renaissance in recent years. While the basics of the sprint start are the same for each athlete, they have considerable freedom to select their own preference for the block settings. These include the distances of the block pedals from the starting line, the distances between the two block pedals and the angle of each block pedal. The two major papers on the influence of different block pedal angles are from Guissard, Ducheteau and Hainaut (1992) and Mero, Kuitunen, Harland, Kyröläinen and Komi (2006). Guissard et al. (1992) used three variations in the front block pedal angles (30°, 50° and 70° to the ground) with the rear block pedal angle being constant at 70°. The decreasing front block pedal angle lengthened gastrocnemius and soleus muscles at the set position prior to a powerful contraction potentially enabling them to be in a more effective position on the muscles' length-tension relationship. Consequently, they observed an increased horizontal start velocity with more oblique front block pedal angles. Mero et al. (2006) demonstrated similar kinds of results with the lower block pedal angle (of 40°) increasing the block exit velocity probably due to longer initial muscle-tendon lengths of these triceps surae muscles contributing to the larger peak ankle moments and power. However, they analysed only two block settings of 40° and 65° (the same angle was set for the both block pedals), while athletes have considerably more variations available for them including setting the different angle for each block pedal. As shown in these two studies, the actual block pedal angles depend on the blocks used in the respective studies (or by athletes in the competition, as different stadia have different manufacturers' blocks). Furthermore, neither of the aforementioned studies used the horizontal external power as their outcome, which has since then been shown to be a more objective performance measure of the sprint start (Bezodis, Salo & Trewartha, 2010).
The aim of this study was to understand how different block pedal angles with typical variations available for the athletes would influence force production and the performance of the sprint start.

METHODS: In order to understand the phenomenon itself (rather than the specific setting that competitive athletes are accustomed to), we recruited active university students who were familiar with sprint acceleration (e.g. in football), but had not used starting blocks. After ethical approval, 15 participants (mean ± SD age, mass and height were 20 ± 1 yr, 71.8 ± 10.8 kg and 1.77 ± 0.08 m, respectively) volunteered for the study and signed an informed consent form.

These participants were trained over five 1 hr training sessions in three weeks on how to perform the block start with an experienced coach before the actual data collection. Each training session contained a self-paced warm-up and 12 to 15 sprint starts from the blocks. The block pedal distances were kept individually the same for each participant throughout the study with typical settings of their own two foot-steps from the starting line to the front block and a step between the block pedals. The block pedal angle was constantly changed in a random order from one start to another, so that the participants would not get used to any specific setting more than another setting. The variation of block pedals angles to induce different lengths of the leg muscles were (as front block/rear block) 40°/40°, 40°/50°, 40°/60°, 50°/50°, 50°/60° and 60°/60°. The same starting blocks (Pro Olympic, Neuff, Norton-on-Derwent, England) were used throughout the whole study including the data collection.
For the data collection, four force plates (900 mm x 600 mm, sampling at 1000 Hz, model 9287BA; Kistler Instruments Ltd., Switzerland) positioned in a 2-by-2 formation were covered with synthetic rubber mats. The starting blocks were set with two separate spines of the blocks and force data were collected as in Salo, Colyer, Chen, Davies, Morgan and Page (2017). Additionally, 15 infrared cameras (Oqus, Qualisys AB, Gothenburg, Sweden) were set around the force plates and the starting blocks area.
The participants completed a warm-up containing 5 minutes on a bicycle ergometer, some running and stretching before 38 reflective markers (22 individual markers and 4 x 4 clusters) were attached to the legs and pelvic area. After a static trial, four medial markers were removed for the actual trials. The participants continued some warm-up including 2-3 practice starts. All participants performed 5 m starts with all six block pedal angle combinations three times each in a fully random order with 2-3 minute intervals between the starts.
Force data were filtered with a second-order low-pass Butterworth filter with a cut-off frequency of 64 Hz derived through residual analysis in Matlab® (Mathworks, Natick, MA, USA). Force and centre of mass velocity variables were calculated as in Salo et al. (2017). Centre of mass projection angle was calculated as the resultant direction from the horizontal and vertical block exit velocities of the centre of mass.
Kinematic data were analysed in Visual 3D software (C-Motion Inc., Germantown, MD, USA), Marker trajectories were low-pass filtered with a 17-Hz cut-off frequency based on residual analysis in Matlab®. A seven-segment model comprising the pelvis and bilateral thigh, shank and foot segments was then constructed using the static calibration trial, in which the local coordinate systems of the segments were defined. The x, y and z axes for each segment related to the mediolateral, anteroposterior and longitudinal rotational axes, respectively. Lower-limb joint angles were defined as the relative orientation of the distal segment in relation to the proximal segment described using an X-Y-Z Cardan sequence, and only the set position data were used for this analysis.
Linear mixed modelling (SPSS Statistics v.22) was used to assess for differences in average horizontal external power, as well as the kinematic and kinetic variables of interest during the block phase, between block angle conditions. Fixed effects in the model were condition and trial number with the participant entered as a random effect. Estimated marginal means (i.e. adjusted for the influence of trial number and the random effect of each participant) ± 90% confidence intervals (CI) for each condition were output from the model and least significant difference post-hoc tests were used to assess for differences across conditions. An alpha of $p<0.05$ was used to evaluate statistical significance.

RESULTS: Average horizontal external power was reduced when a 60° block angle was used in comparison to lower block angles (Figure 1). The horizontal block exit velocity (estimated marginal means varying from 2.8 to 2.9 m/s across the conditions) follows closely the same pattern including the statistically significant differences. The results from the selected key variables are presented in table 1 with angular data taken from the set position to indicate the initial body configuration before the active push-off against the blocks started.

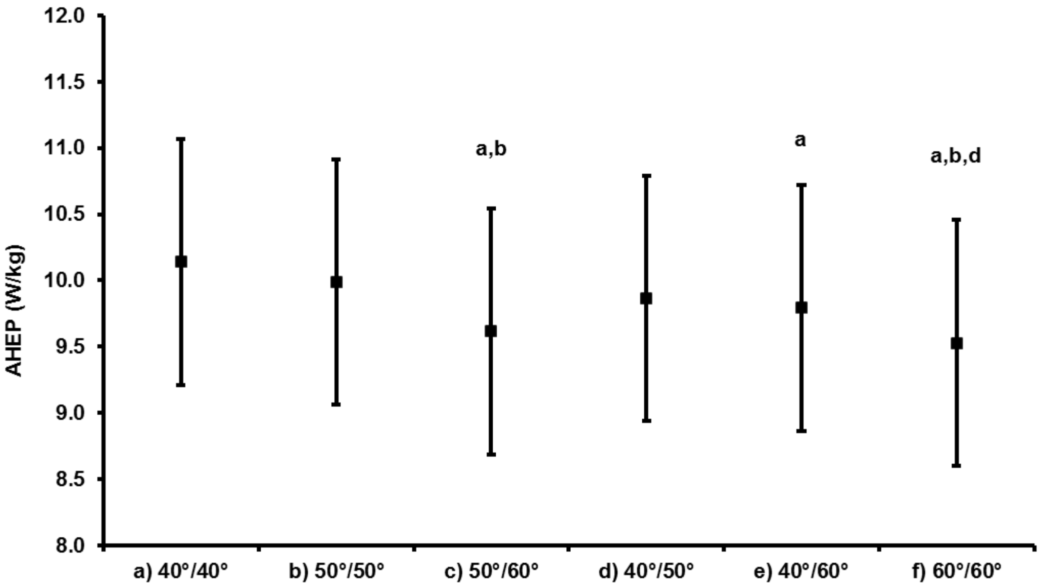

Figure 1. Average horizontal external power (AHEP; estimated marginal means ± 90% CI) across the six block settings. a, b, and d on the top of CI bars denote statistically lower results (*p*<0.05) than the respective conditions on the label of x-axis.

Table 1. Estimated marginal mean values for the key variables with letters denoting statistically lower results (*p*<0.05) than the respective conditions. Angle data are from the set position. CM = centre of mass, A-P = anterior-posterior.

Condition:	a) 40°/40°	b) 50°/50°	c) 50°/60°	d) 40°/50°	e) 40°/60°	f) 60°/60°
Mean resultant force [N/kg]	13.4	13.4	13.3	13.3	13.3	13.1
p<0.05			a	a	a	a,b,c,d,e
Mean horizontal A-P force [N/kg]	7.0	6.9	6.8	6.9	6.9	6.7
p<0.05			a		a,b	a,b,c,d,e
Mean vertical force [N/kg]	11.0	11.0	10.9	10.9	10.9	10.8
p<0.05			a	a,b	a,b	a,b,c,d,e
CM vertical velocity [m/s]	0.51	0.50	0.48	0.45	0.46	0.40
p<0.05				a,b	a,b	a,b,c,d,e
CM projection angle [°]	9.9	9.7	9.6	8.9	9.1	8.0
p<0.05				a,b	a	a,b,c,d,e
Rear leg ankle angle [°]	107	111	117	112	118	118
p<0.05	b,c,d,e,f	c,e,f		c,e,f		
Rear leg knee angle [°]	126	123	119	124	122	120
p<0.05		a	a,b,d,e	a	a,d	a,b,d
Rear leg hip angle [°]	107	104	102	106	103	105
p<0.05		a,d	a,b,d,e,f	a	a,b,d,f	a,d
Front leg ankle angle [°]	115	115	115	120	119	127
p<0.05	d,e,f	d,e,f	d,e,f	f	f	
Front leg knee angle [°]	105	106	105	104	105	102
p<0.05						a,b,c
Front leg hip angle [°]	77	77	78	76	77	76
p<0.05	c	c		c,e		c

DISCUSSION: Variation of the block pedal angles resulted in statistically significant changes in average horizontal external power across the conditions as shown in Figure 1. The different block pedal angles induced considerable and statistically significant differences in the body configuration at the set position. Changes across the conditions also yielded differences in force production variables, the consequent block exit velocities and the centre of mass projection angle (table 1). Due to the nature of the participants, it was clear that the mean horizontal block exit velocity would be less than fully-trained sprinters, nevertheless, this was only about 15% lower than by the competitive sprinters in Mero et al. (2006) showing that the participants had reached a good level of performance due to their training.
The main reason for the reduced horizontal average power in block pedal angles of 60° was the reduced block exit velocity (i.e. impulse produced). In these steeper block pedal angles, the overall resultant force production decreased (together with both of its components). Furthermore, the force production was orientated more horizontally (see centre of mass projection angle in table 1). While this could be considered beneficial per se, it may have become too low for the effective block exit, as the power values showed. The main reason behind the reduced force production is likely to be the body configuration at the set position, which is the starting point of the active push-off. As shown by Guissard et al. (1992) and Mero et al. (2006), varying the block obliquity changes the muscle-tendon lengths especially for the soleus and gastrocnemius. When coupling ankle and knee angle information at the set position in this study, we can see that at lower block pedal angles the calf muscles are more stretched. This may provide better pre-stretching and more optimal muscle-tendon length to produce more force by these muscles throughout the movement, and also the ankle has an opportunity for a larger plantar-flexion range than with steeper block pedal angles. Mero et al. (2006) demonstrated that the increased triceps surae muscle length at 40° block pedal angle (in comparison to 65°) may have increased joint moments and power at the push-off. Bezodis, Salo and Trewartha (2015) showed the importance of hip extension during the block phase. When combining the joint angle data of knee and hip, it is likely that the hip extensor muscles were not lengthened in a similar fashion to the triceps surae. Thus, while the hip extensors are important for the start phase, the main differences in force production between the varying conditions in this study might have come from the calf muscles.

CONCLUSION: Varying the starting block pedal angles clearly induced body configuration changes at the set position. Probably due to more favourable calf muscle-tendon unit lengths for force production, better starts were performed with the lower rather than the steeper block pedal angles by these non-experienced, but coached participants. As anecdotally elite athletes tend to have slightly steeper block pedal angles, a further investigation is warranted whether improved muscle strength would change the best block pedal angles for individuals.

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