3D Kinematic of Bunched, Medium and Elongated Sprint Start

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Key words
- sprint
- running
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Abstract

The aim of this study was to test the influence of 3 different horizontal distances between the blocks (bunched, medium and elongated) on the velocity of the centre of mass (V_{CM}) and the kinetic energy (KE) of the body segments and of the whole body. 9 well-trained sprinters performed 4 maximal 10 m sprints. An opto-electronic Motion Analysis® system (12 digital cameras 250 Hz) was used to collect the 3D trajectories of 63 markers during the starting block phase. The results demonstrated that the elongated start, compared to the bunched or medium start, induced an increase of V_{CM} at block clearing (2.89 ± 0.13; 2.76 ± 0.11; $2.84 \pm 0.14\, m.s^{-1}$) and a decrease of the performance at 5 and 10 m. Both results were explained by a greater pushing time on the blocks in the elongated condition. During the starting block phase, the KE of the whole body was greater in the elongated start (324.3 ± 48.0 J vs. 317.4 ± 57.2 J, bunched and 302.1 ± 53.2 J, medium). This greater KE of the whole body was mainly explained by the KE of the head-trunk segments. Thus, to improve the efficiency of the starting block phase, the athlete must produce greater KE of the head and trunk segments in the shortest time.

Introduction

To perform their best performance, the faster sprinters in the world have reached a very high running velocity (around 11.98–12.42 $m.s^{-1}$). To reach this high velocity, the starting block phase is extremely important in a 60 m and 100 m sprint [2,3,11,13,14,17]. This phase is greatly influenced by the adjustment of the block positions (spacing and obliquities) [4,5,6]. Indeed, each sprinter is authorized to adapt the starting block adjustment in regard to his best "sensation", time or morphology.

One of the most popular adjustments that is usually modified by the sprinters is the horizontal distance between the blocks. There are the bunched start (spacing generally <30 cm), the medium start (30–50 cm) and the elongated start (>50 cm) [6]. Biomechanical studies have shown that the velocity of the centre of mass (V_{CM}) at block clearing is higher when the inter-block spacing increases due to a more effective force-impulse [1,8,10,15]. This is linked to a longer duration of force production on the blocks and a larger contribution of the rear leg to the total force impulse [6]. In these conditions, the advantage of a higher start velocity is associated with a longer pushing time on the blocks compared with the bunched start [4,8,16]. Henry [8] and Sigerseth and Grinaker [16] found that the medium start is the best compromise because it allowed the sprinters to obtain their best performances at 20 and 50 yards (i.e 18.3 and 46.7 m).

According to Kisler [10] or Henry [8] the biomechanical tools and the morphology of the sprinter have been considerably modified. Previous 2D study [1,15] using kinematic data reduced their analysis to provide only centre of mass (CM) position and velocity measures. However, the position and the velocity of the CM depend on the position and the velocity of the different body segments. To understand the contribution of each segment in the translational movement of the CM during the sprint start, the use of a whole body 3D biomechanical model is essential to have some information about the influence of the movement in the 3 planes. Moreover, the use of the kinetic energy (KE) of the body segments supplies useful information concerning the upper and lower limbs' contributions to the translation of the body in the forward direction during the starting block phase [9,17].

To our knowledge, no study analysed the influence of block spacing on KE of the body segments

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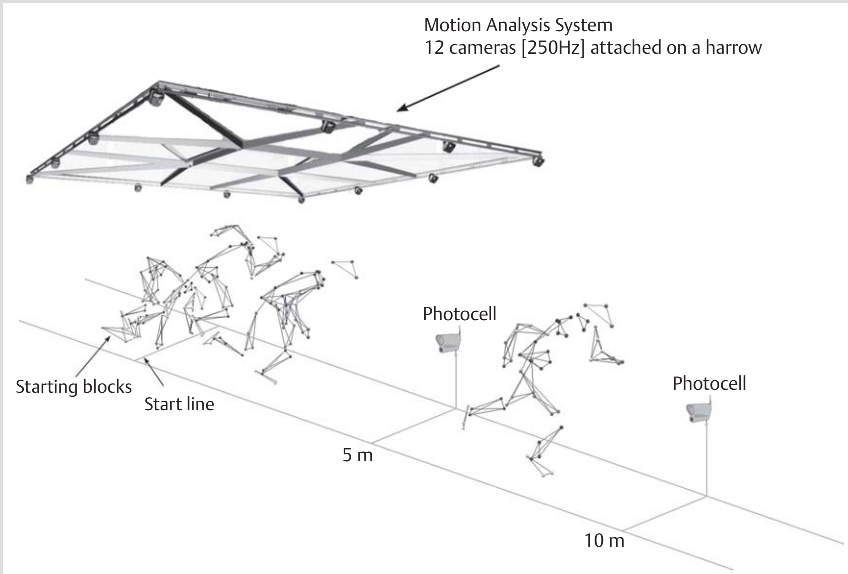

Fig. 1 Experimental protocol.

and its relationships with the V_{CM} during the first meters of the sprint i.e. between 5 and 10 m. That is why, the first objective of this study was to test the influence of 3 different horizontal distances between the blocks (bunched, medium and elongated) on the position of the CM, the velocity of the CM (V_{CM}) and the KE of the body segments of well-trained sprinters. Furthermore, from this study, it could be possible to bring some new indications for the coaches about the influence of the different horizontal adjustments on the body organisation of the athletes during the block phase. The relevance of the 3D biomechanical model may well bring more accurate and relevant indicators for the coaches and for the analysis of their athletes.

For this, a 3D biomechanical model developed for the whole body and taking into account the ISB recommendations has been used. It was hypothesised that the modification of the posture due to different horizontal distances between the blocks leads to KE modifications. In addition, a greater velocity of the centre of mass should be associated with greater KE of the body segments.

Methods

Subjects

9 trained sprinters composed of 3 women and 6 men took part in this study. They were between 17 and 24 years of age, and respective heights ranged from 169.0 ± 2.6 cm for the women and 180.3 ± 7.2 cm for the men. Their weight ranged from 57.7 ± 3.8 kg for the women and 74.7 ± 6.9 kg for the men. The sprinters had a national level and trained together at least 6 times a week. Their training background was 5–7 years. Their best time over 100 m ranged from 11.61 ± 0.42 s for the women and 10.58 ± 0.27 s for the men. All the sprinters gave their informed written consent to participate in the study. This study conforms to the recommendations of the Declaration of Helsinki [8], and had been approved by the local Ethics Committee.

Procedures

The experiment was realized in April just before the period of competition. The sprinters were in the tapering phase of their training program. The experiment was placed in the morning, during their usual training session. The sprinters started using 3 different horizontal inter-block spacing on an indoor track with standard starting blocks (▶ **Fig. 1**). A first horizontal adjustment corresponded to the bunched start (the inter-blocks spacing was 21.5 ± 3.2 cm). A second horizontal adjustment corresponded to the medium start (the inter-block spacing was 36.8 ± 3.5 cm). A third horizontal adjustment corresponded to the elongated start (the horizontal inter-blocks spacing was 54.8 ± 3.8 cm). The different adjustments were made by moving only the rear block. The block's obliquity was the same for each condition. Each starting condition was repeated 3 times, thus each sprinter performed a total of 9 maximal 10 m sprint starts. The rest between trials was comprised within 5–7 min. Each of the 3 starting conditions was randomized for each athlete. It is important to note that the sprinters usually start with a medium start. In order to get used to the different inter-block spacing they had a period of 4 training sessions before the experimental session.

The sprinter were equipped with 63 passive reflective markers, and an opto-electronic Motion Analysis® system (12 digital cameras 250 Hz) was used to collect the 3D marker trajectories during the pushing phase on the blocks and the first step [17].

Data analysis

In order to analyse the results, different critical instants were identified: on your marks, set position, block clearing and toe-off of the first step. From these instants, 2 phases were defined, the starting block phase (when the runner is in contact with the block) and the first step.

Time

The reaction time (RT) was measured with a reactime™ (Microgate, Bolzano, Italy). The time at 5 m and 10 m (T5 and T10) was recorded using photocells (Microgate, Bolzano, Italy). The height of the photocells was set at 1 m.

Position, velocity of the CM and kinetic energy

For this study, 16 rigid segments were used in order to model the body: head-neck, thorax, abdomen, pelvis, front and rear arms, forearms, hands, thighs, legs and feet. Rear and front joints were respectively associated with the side of the rear and the front legs in the starting blocks.

The CM was computed as the barycentre of the segments and, at each critical instant, the vertical and horizontal positions of the CM (X_{CM} and Y_{CM}), and the norm of the velocity of the CM (V_{CM}) were calculated. The maximal value of the KE (KE_{max}) was calculated for each body segment and for the whole body. The computation of the CM, V_{CM} and KE was done with Matlab software.
The details of the segment definition, inertial parameters and KE calculation have been given in a previously published work [17].

Statistical analyses
For each parameter measured, and at each critical instant a normality test was completed. Then, a comparison of the data between bunched, medium and elongated starts was performed with an analysis of variance for repeated measures (ANOVA). A Bonferroni post hoc analysis was then performed. All statistical analyses were conducted at $P<0.05$. All the statistical analyses were performed with Statview® software.

Results
▼
Time
Table 1 shows that pushing time on blocks and time at toe-off are significantly greater for the elongated start compared to bunched or medium start. Significant effect of the inter-block spacing is also observed for the reaction time, however, post hoc analysis does not show any significant differences between the elongated start and others. Concerning the time at 5 m, the ANOVA shows a significant difference between the 3 adjustments. Post-hoc analysis shows that T5 is lower for bunched start compared to elongated start. At 10 m, T10 is significantly lower for medium start compared to elongated start.

Table 1 Reaction time (RT), time of block clearing, time of toe-off of the 1st step, time at 5 and 10 meters (T5 and T10) for bunched, medium and elongated conditions ($p \leq 0.05$).

	Bunched (±SD)	Medium (±SD)	Elongated (±SD)
RT (s)	0.183 ± 0.036	0.171 ± 0.031	0.159 ± 0.028†
blocks clearing (s)	0.371 ± 0.016	0.377 ± 0.017	0.427 ± 0.056†*§
toe-off 1st step (s)	0.632 ± 0.020	0.636 ± 0.020	0.686 ± 0.064†*§
T5 (s)	1.362 ± 0.064	1.375 ± 0.056	1.402 ± 0.038†*
T10 (s)	2.102 ± 0.079	2.097 ± 0.084	2.134 ± 0.057†§

† Significant effect of the inter-block spacing (ANOVA)
* Significantly different from bunched position (post-hoc analysis)
§ Significantly different from medium (post-hoc analysis)

Position and velocity of the CM
The results (**Table 2**) showed that, in the position "on your marks" and "set", the X_{CM} is smaller for the elongated start. Y_{CM} is not influenced by the inter-block spacing. The ANOVA shows that the V_{CM} is greater for the elongated start at block clearing and at the toe-off of the first step compared to the bunched start.

Kinetic energy
Significant KE differences appear during the starting block phase. Indeed, KE_{max} of the whole body is significantly greater for the elongated start compared to the bunched start (respectively for bunched, medium and elongated, 302.1 ± 53.2 J, 317.4 ± 57.2 J and 324.3 ± 48.0 J; **Fig. 2**). The study of the different segments shows that the KE_{max} of the head-neck, thorax, abdomen and pelvis are also significantly greater for the elongated start compared to the bunched start (**Fig. 3**). Concerning the KE of the upper and lower limbs, the results show that KE_{max} of the front forearm and front hand are significantly lower for the elongated start compared to medium and bunched start (**Fig. 4**). Inversely, the KE_{max} of the rear thigh, leg and foot are greater for the elongated and medium start compared to bunched start (**Fig. 4**).

Discussion
▼
Actually, the results obtained from the accuracy of 3D biomechanical models could help the coach to understand which postural adjustments are used in these 3 different block positions [17, 18]. In this context, the aim of this study was to analyse the impact of the block adjustments on the position of the CM, on its velocity and on the KE during the first meters of the sprint. The results showed that the position of the starting block modified the position, the V_{CM} of the total body and the KE of the different limbs. This study highlights the importance of the contribution of the head and trunk limb movements to create a high V_{CM} during the starting block phase.
The primary effect of the modification of block spacing was to induce natural postural adaptations of the sprinters. Indeed, during the pushing block phase, the distance travelled by the CM in the elongated condition start is greater than in the medium or bunched condition (**Table 1**). This increase of distance travelled by the CM is explained by the fact that the body moves back in the set position. It should be noted that the X_{CM} in the set position is significantly smaller in the elongated start. This result can be explained by the modification of the rear foot position in

Table 2 For bunched, medium and elongated conditions the different kinematic and kinetic parameters are: horizontal and vertical positions of the CM (X_{CM}; Y_{CM}), rear and front knee angles, velocity of the centre of mass (V_{CM}) at block clearing and the toe-off of the first step ($p \leq 0.05$).

		Bunched (±SD)	Medium (±SD)	Elongated (±SD)
XCM (cm)	on your marks	−24.4 ± 4.7	−28.6 ± 3.5	−33.8 ± 4.5†*§
	set	−21.7 ± 2.0	−25.2 ± 1.9*	−30.9 ± 3.0†*§
	block clearing	37.2 ± 3.7	37.5 ± 2.9	37.1 ± 3.0
	toe-off 1st step	37.2 ± 3.7	37.5 ± 2.9	37.1 ± 3.0
YCM (cm)	on your marks	49.9 ± 3.1	50.1 ± 2.7	50.1 ± 2.3
	set	66.6 ± 2.4	66.5 ± 2.9	65.5 ± 2.9
	block clearing	82.0 ± 3.1	82.2 ± 3.0	82.4 ± 3.5
	toe-off 1st step	84.9 ± 4.3	85.5 ± 4.4	86.0 ± 5.2
VCM ($m.s^{-1}$)	block clearing	2.76 ± 0.11	2.84 ± 0.14*	2.89 ± 0.13†*
	toe-off 1st step	3.81 ± 0.18	3.85 ± 0.16	3.90 ± 0.15†*

† Significant effect of the inter-block spacing (ANOVA)
* Significantly different from bunched position (post-hoc analysis)
§ Significantly different from medium (post-hoc analysis)

the initial posture of the sprinter in the blocks. The more the rear foot is back, the more the CM is back, too. Besides, it is important to note that this greater distance travelled by the CM in the elongated start is not linked to a modification of the position of the CM at the end of the pushing block phase. Whatever

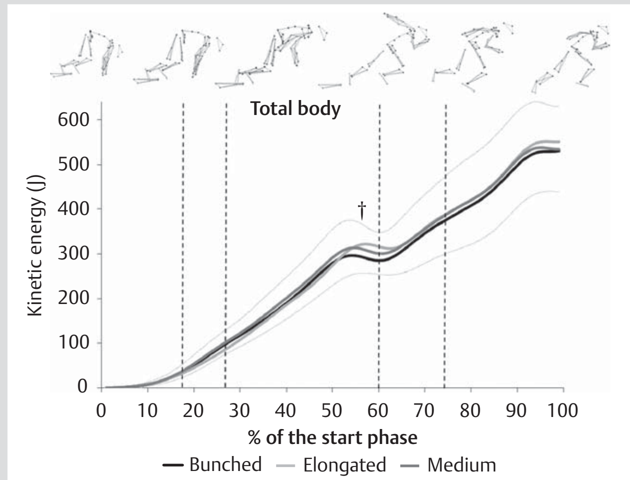

Fig. 2 Kinetic energy of the total body. †Significant effect of the inter-block spacing (ANOVA) on the maximal kinetic energy of the considered system. The standard deviation corresponds to the data of the medium start. Vertical bars correspond respectively to the hands clearing, rear foot clearing, block clearing and landing of the first step.

the initial block position, the position of the CM at the clearing block does not change. Finally, the sprinters using an elongated start travel more distance than their counterparts.

As regards the natural postural adaptations of the sprinter in the blocks, the V_{CM} is also modified by the block adjustments. The present results showed that the elongated condition induced a greater V_{CM} at the block clearing (Table 2). From a biomechanical point of view, the ability to leave the blocks at a high velocity depends on the impulse during the pushing phase on the blocks. The impulse of a movement is defined as the area under the force-time curve. Thus, the size of this area depends on 3 main parameters: the duration of force application, the rate of force development and the maximal force reached. In the elongated condition, it should be noted that the duration of force application is increased during the pushing block phase. Thus, the greater V_{CM} at block clearing could be due to the increase of the pushing time on the block. However, despite a greater V_{CM} for the elongated start, the performances at 5 and 10 m are significantly worse compared to the bunched start. Thus the use of the elongated start is not recommended for the short distance sprinters. Henry [8] and Sigerseth and Grinaker [16] previously found this results and suggested that the pushing time in the elongated start is too large to be regained at 5 and 10 m. Henry [8] concluded that the bunched start allows obtaining a shorter time at 5 m, but the medium start offers the best compromise to the sprinter because this advantage of time decreases at 10 m. The present results are in line with this earlier finding because at 10 m the medium start allows the sprinter to realize his better

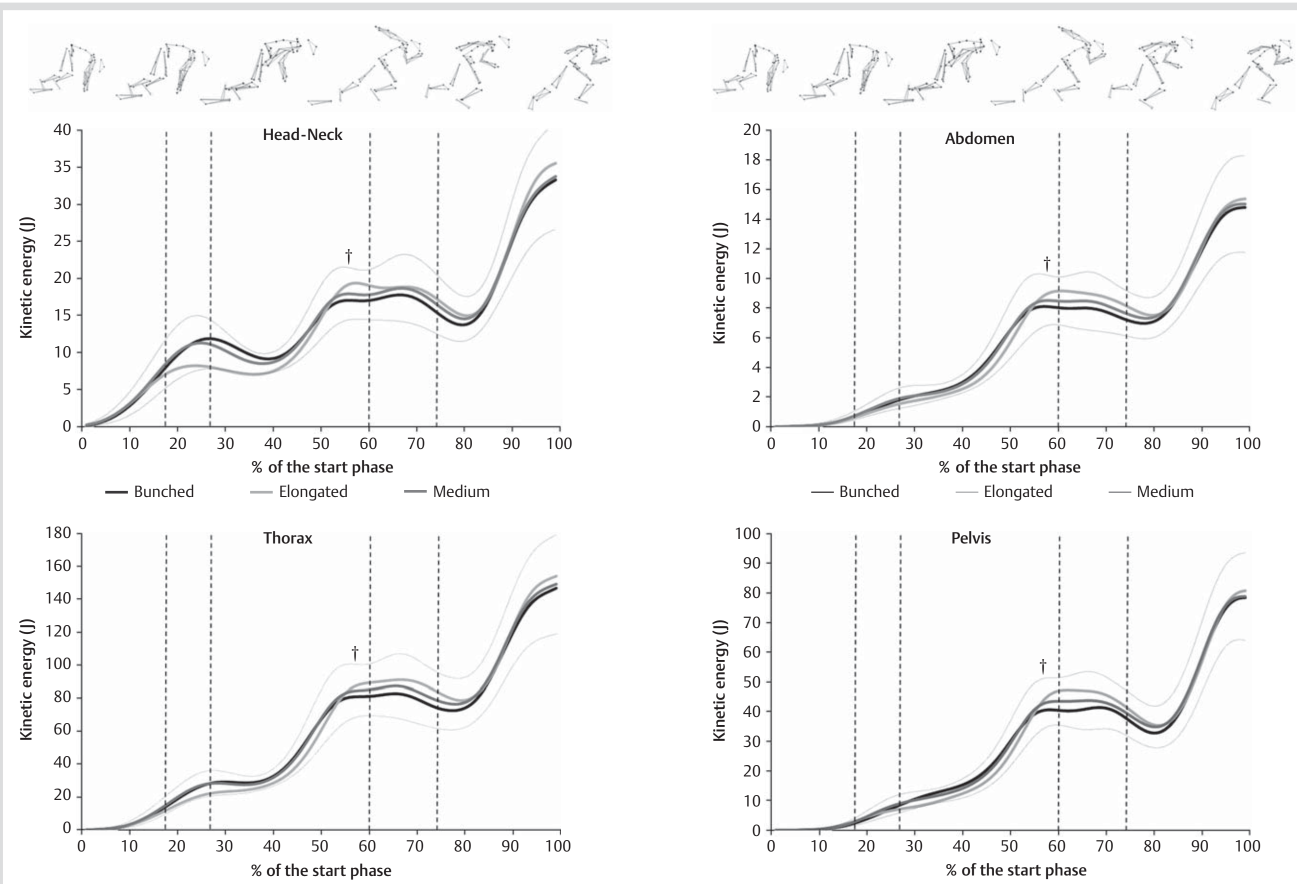

Fig. 3 Kinetic energy of the head-neck, abdomen, thorax and pelvis. †Significant effect of the inter-block spacing (ANOVA) on the maximal kinetic energy of the considered system. The standard deviation corresponds to the data of the medium start. Vertical bars correspond respectively to the hands clearing, rear foot clearing, block clearing and landing of the first step.

performance. However, it is important to note that the medium start was the type of start usually used by all the sprinters tested. This observation, despite a period of training before the experiment in order to get used to the bunched and elongated start, could explain a better time at 10 m with the medium start. Moreover, another limitation of this study is the number of sprinters recorded during the training session. Indeed, to confirm these results it could be pertinent to take into account a larger number of sprinters and to distinguish between men and women in a future analysis.

As the V_{CM}, the KE of the segments and of the total body is modified by the block adjustments. The present results showed that the elongated condition induced a greater KE_{max} of the whole body (▶ **Fig. 2**). To understand this result, the analysis of the KE of each segment is necessary. Thus, it appears that the KE_{max} of the head-neck, thorax, abdomen and pelvis is significantly greater in the elongated start. These limbs contribute for 40 % to the KE of the whole body. This demonstrates that their actions in the pushing phase on the blocks are essential. Therefore, the present study highlights the role of the head and trunk limbs in this phase (according to their greater masses). To perform a more effective start, the sprinters must increase the KE_{max} of the whole body and thus the KE_{max} of the head and trunk limbs. However, an increase of this KE_{max} seems to be possible thanks to a longer duration of the starting block phase. The greater pushing time on the block may allow the sprinter to give a greater velocity to his head and trunk segments, but decreases his performance at 5 and 10 m. From this result concerning the

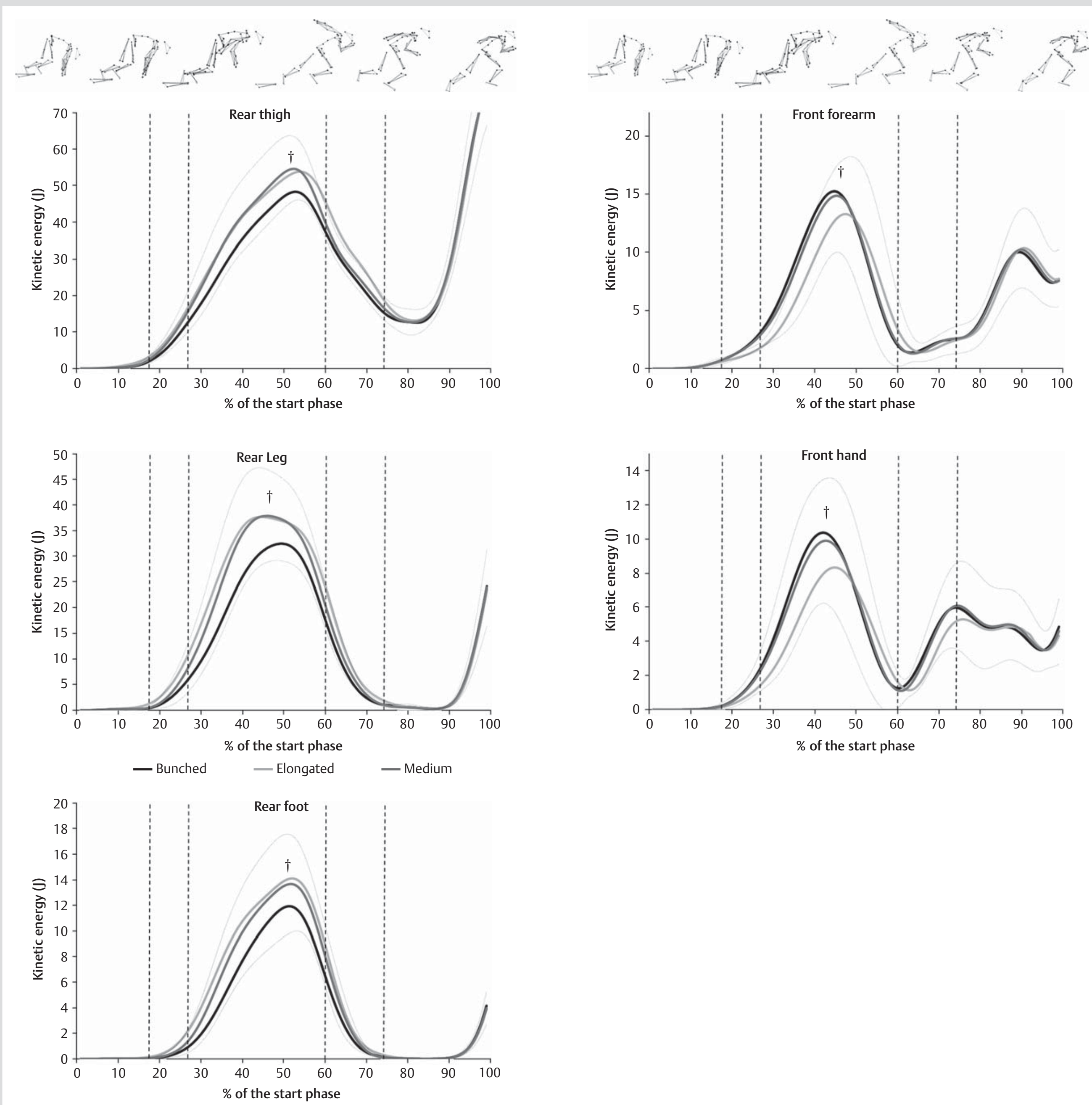

Fig. 4 Kinetic energy of the rear thigh, leg and foot (left panel). Kinetic energy of the front forearm and hand (right panel). †Significant effect of the inter-block spacing (ANOVA) on the maximal kinetic energy of the considered system. The standard deviation corresponds to the data of the medium start. Vertical bars correspond respectively to the hands clearing, rear foot clearing, block clearing and landing of the first step.

head and trunk limbs, it should be recommended to the coach that to improve the efficiency of this phase, a specific training could produce a greater KE of the head and trunk in the shortest time.

Concerning the lower limbs, it appears that the rear foot, leg and thigh contribute to the increase of the KE_{max} of the whole body. Indeed, the elongated start induces an increase of the KE_{max} of the rear foot, leg and thigh. Moreover, the KE_{max} of these limbs represent 28% of the KE_{max} of the whole body. This result confirms the data obtained by Kraan et al. [12] who suggested that starting with the leg backwards results in higher kinetic energy of this leg. Finally, the KE_{max} of the front hand and forearm decrease in the elongated start compared to the bunched start. However, this decrease has few consequences on the KE_{max} of the whole body because KE_{max} of the front hand and forearm represents only 7% of the KE_{max} of the whole body. Thus, to understand the contributions of each segment to the movement of the CM in the forward direction, it appears the the KE is a useful tool [17].

Conclusion

In summary, the main points emerging from this study are as follows: (1) the elongated start induced an increase of the velocity of the CM at the block clearing linked to an increase of the pushing time on the blocks. (2) This increase of the pushing time leads to a decrease of the performance at 5 and 10 m. (3) The elongated start induced a greater KE of the total body and more particularly concerning a greater KE of the head-neck, thorax abdomen and pelvis.

From a practical point of view, 2 important recommendations could be made. Firstly, the elongated start should not be used in short distance sprinters. Secondly, in order to improve the efficiency of the starting block phase, specific exercises increasing the "explosiveness" of the extensor muscles of the trunk and of the flexor muscles of the hip should be included in the training program.

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